Journal of Life Sciences 9 (2015) 120-126
doi: 10.17265/1934-7391/2015.03.005

Uncertainties of "*in vivo*" Dosimetry Using Semiconductors

Zeina Al Kattar, Hanna El Balaa and Saeed Zahran
Faculty of Sciences, Lebanese University, Beirut, Hadath, Lebanon

Received: April 17, 2015 / Accepted: April 30, 2015 / Published: April 30, 2015.

Abstract: The purpose of the present study is to evaluate the uncertainties of *in vivo* dosimetry measured with diode detectors for conformal radiation therapy techniques in order to define appropriate tolerance levels for pelvis and breast treatment in MEIH (Middle East Institute of Health). The present work is carried out on 30-472 and 30-473 diode detectors irradiated by 4 and 15MV photon beams of a medical linear accelerator Synergy from ELEKTA. Dose computation is performed with Pinnacle 7.4 k treatment planning system. First, an estimation of the uncertainties in a simple geometric case, using a water-equivalent solid phantom is done. Secondly, each treatment parameter such as field size, beam angle, beam modifiers and source-skin distance is evaluated in order to simulate the conformal radiation treatments used in the present institution for the main anatomical sites. Interpretation of entrance dose in-vivo measurements requires the determination of appropriate tolerance levels. Indeed, the authors found that the 5% action level proposed in the literature underestimates the uncertainties in the treatment process. A method for the evaluation of tolerance/action levels related to the different anatomical sites is developed. By the end of the present study the authors have developed an integrated monitoring system that offers accurate information about the dose received by patients.

Key words: *In vivo* dosimetry, conformal radiation therapy, entrance dose, diode detectors, uncertainties, tolerance levels, integrated system.

I. Introduction

The goal of radiation therapy is local tumor control. To achieve optimum results, the tolerance of the dose deviation is very narrow for tumor local control and minimal risk morbidity for healthy tissue. The purpose is to safely, accurately, and efficiently deliver radiation to treat various types of malignant and nonmalignant abnormalities. The sophistication of treatment carries the risk of errors due to both human operations and technical failures [1]. In order to detect these errors, prevent and limit the frequency of errors, it is necessary to implement a program of quality assurance. Recently, a number of radiation incidents in various countries have been reported [2]. In addition to incidents caused by human errors, suboptimal patient treatments may also occur because one or more of the parameters involved in a patient irradiation may have a systematic error. To address these issues comprehensive QA (quality assurance) programs have been introduced [3]. *In vivo* dosimetry measurements are the most important stage of this quality assurance program [4]. The purpose of the following study is to evaluate the uncertainties of *in vivo* dosimetry measured with diode detectors for conformal radiation therapy techniques in order to define appropriate tolerance levels for pelvis and breast treatment in Middle East Institute of Health MEIH. Developing an integrated monitoring system that offers accurate information about the dose received by patients including these uncertainties is of great importance, too.

2. Methodology

The present approach will first, identify and estimate the uncertainties in dose measurements by

Corresponding author: Zeina Al Kattar, Ph.D., research fields: radiotherapy, radiology, nuclear physics. E-mail: zeinakattar1@hotmail.com.

semiconductor detectors using water equivalent phantom in simple geometric conditions. In a second step, the authors will successively vary each of the processing parameters (field size, source skin distance, obliquity of the beam, position of the diode...) in order to gradually increase the complexity of the radiation beam configuration to be closer to clinical conditions and quantify associated uncertainties.

The author will determine in both cases, the uncertainties calculated by the treatment planning system (TPS) and uncertainties related to the semiconductor lecture to calculate the overall difference between these two values of dose.

Finally, an appropriate level of tolerance for in vivo dosimetric checks for conformal radiotherapy is defined. Accurate knowledge of these tolerance intervals will define levels of intervention and optimize the final link in the quality assurance program chain in radiotherapy.

2.1 Identification of Uncertainties in a Simple Geometric Case

The irradiation conditions are the following:

- Phantom water equivalent
- Field size 10 × 10 cm^2
- Incidence of the beam: perpendicular (arm at zero degree)
- SSD (Source surface distance) 100 cm for 4MV and 15MV
- Number of monitor units: 200
- Depth used to the maximum dose is 1.8 cm for 4MV energy photons and 2.8 cm for 15MV energy photons.

(1) Uncertainties on the dose calculated by the TPS: For a simple geometric case, the authors evaluate the uncertainty about the reproducibility of the dose calculation due to repositioning of the grid (type A uncertainty).

(2) Uncertainties on the dose measured in the phantom are evaluated.

The measured dose by the semiconductor in the calibration conditions:

$$D_{entrance} = R_{entrance,diode} * F_{cal} \quad (1)$$

To determine the overall uncertainty on measured dose "$D_{entrance}$" the authors seek the uncertainties on the term of reading diode at the maximum dose depth "$R_{entrance}$" and secondly the term of calibration factor F_{cal}.

- Uncertainties of $R_{entrance}$ takes into account:

- The reproducibility of the measurement diode chain, cable and electrometer is a type A uncertainty;
- The reproducibility of the mounting is type A uncertainty, too.

- Uncertainties of F_{cal}

The calibration factor is previously measured using the ionization chamber:

$$F_{cal} = [\frac{D_{ic}}{R_{diod}}]_{ref.condition} \quad (2)$$

The authors must therefore take into account the uncertainties related to the maximum dose and to the diode.

- Uncertainties of for dose (max):

$$Dose_{max} = Reading_{IC} * N_{d,water,Q} * K_{(t,p)} \quad (3)$$

∗Uncertainties related to the reading of ionizing chamber IC: stability of the irradiation beam (type A uncertainty);

∗Uncertainties related to the $N_{d,\ water,\ Q}$: response of the ionization chamber (type B uncertainty);

∗Uncertainties related to the K (t, p): correction coefficient due to changes in temperature and pressure (type B uncertainty).

- Uncertainties related to the diode:

∗ Stability of the radiation beam is type A uncertainty);

- Overall uncertainty on the dose measured on the phantom:

- D_{ic}: dose measured by ionization chamber to the depth of the maximum dose;
- R_{diode}: signal read on the electrometer connected to the semiconductor;
- N_d, water, Q: calibration factor for the ionization chamber in terms of dose absorbed in water for the

quality Q of the beam;

- K (t, p): correction factor for the temperature and pressure.

(3) Overall uncertainty: Overall uncertainty on the difference between expected dose (prescribed dose calculated by the TPS) and dose measured in the water phantom. The final uncertainty on the percentage difference between the expected dose and the measured dose, relying on the formalism described above is determined.

2.2 Identification of Uncertainties in a Complex Geometric Case (Clinical Situations)

Clinical situations such as breast and pelvis treatment are developed in two consecutive steps:

(1) Uncertainties on the dose calculated by the TPS: the authors have taken into account the uncertainty related to heterogeneities calculation of the TPS algorithm (type A uncertainty).

(2) Uncertainties on the measured dose to the patient:

The uncertainties related to the different correction factors applied to calculate the dose received by the patient is evaluated. The dose calculation equation is set by:

$$D_{entrance} = R_{entrance,diode} * F_{cal} * CF \quad (4)$$

$$CF = CF_{fs} * CF_{ssd} * CF_{wedge} * CF_{angle} \quad (5)$$

where CF_{fs} is the correction factor taking into account the field square size, CF_{ssd} is the correction factor taking into account the variation of the source skin distance, CF_{wedge} is the correction factor taking into account the presence of wedge and CF_{angle} is the correction factor taking into account the beams angle.

3. Results and Discussion

The authors give in the present section the main results which have enabled them to meet the problem. In the first part the uncertainties in a simple geometric case are assessed, in a second part the uncertainties in various clinical situations are evaluated.

3.1 Identification of Uncertainties in a Simple Geometric Case

(1) Uncertainties on the dose calculated by the TPS: For the simple geometric case, the uncertainties to be determined are the uncertainties about the reproducibility of the dose calculation due to the repositioning of the grid.

The authors obtain an uncertainty of ± 1.1% in X4 and ± 0.92% in RX15.

(2) Uncertainties on the dose measured on the phantom: The relative uncertainty on the measured dose of ± 2.3% for photons of 4MV and ± 2.4% for photons of 15MV is obtained (or a coverage factor of k equal to 2, range of confidence 95%).

(3) Overall uncertainty on the difference between expected dose calculated by the TPS and dose measured by Diode on the phantom: an overall uncertainty on the phantom of ± 2.54% for photons of 4MV and ± 2.57% for photons of 15MV is obtained.

3.2 Identification of Uncertainties in Clinical Cases

(1) Determination of correction factors: To determine the correction factors, the authors have realized several series of measurements with the SC (semiconductor) and the IC (ionization chamber). Results for the different correction factors for different energies (4MV, 8MV and 15MV) are listed in figs. 1-4.

(2) Overall uncertainty on the difference between expected dose and dose measured on patient: Table 1 presents the results of the authors' calculations for estimating the overall uncertainty of the difference between the expected and the measured dose by the semiconductor by location and energy dose.

4. Embedded *In Vivo* Dosimetry System

An integrated system monitoring is of great importance. It offers exact information about the *in vivo* dosimetry of the patient (Fig. 5).

4.1 Software

The software is written in Visual Basic 2008, the

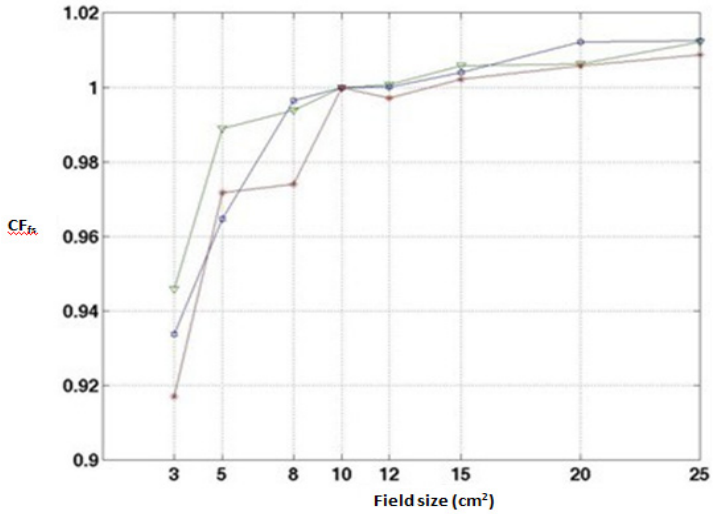

Fig. 1 "CF_{fs}" correction factors in function of field square for (4MV in Red, 8MV in Green and 15MV in Blue) energies.

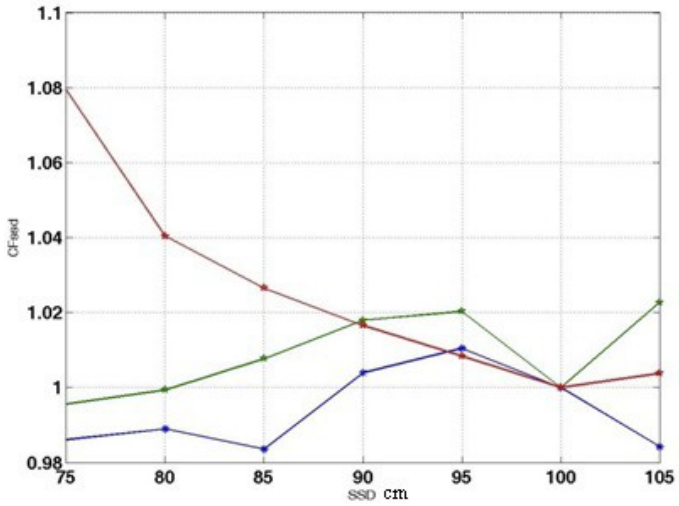

Fig. 2 "CF_{ssd}" correction factors in function of SSD and energies (4MV (Blue), 8MV (Green) and 15MV (Red)).

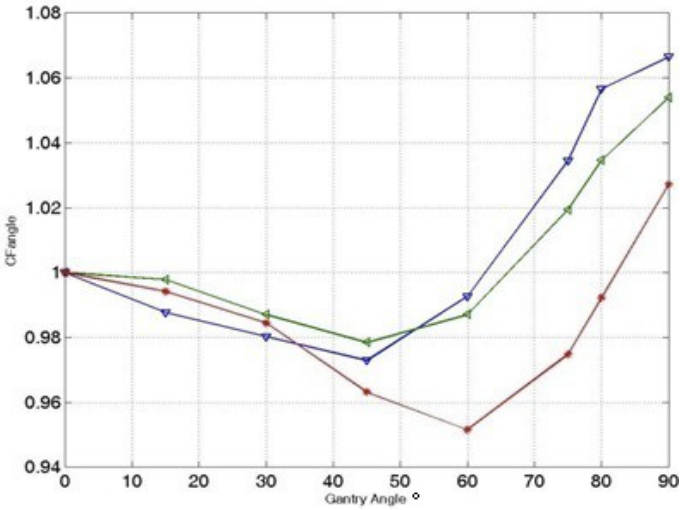

Fig. 3 "CF_{wedge}" correction factors in function of gantry angle and energies (4MV (Blue), 8MV (Green) and 15MV (Red)).

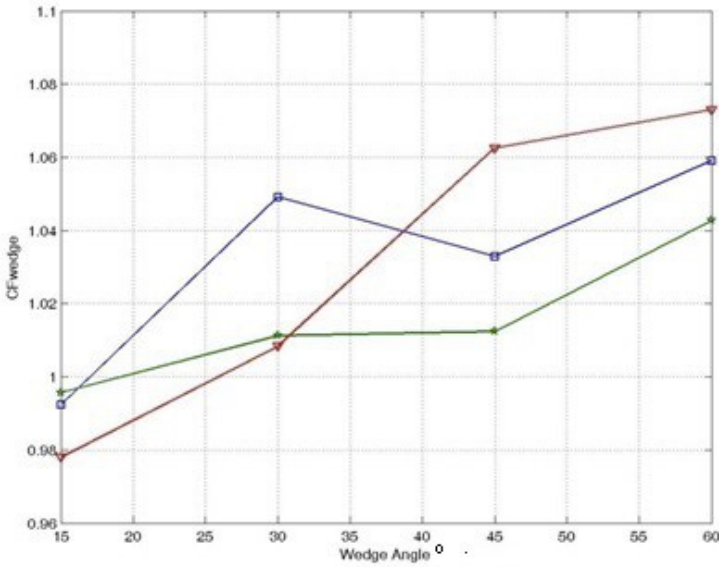

Fig. 4 "CF_{angle}" correction factors in function of wedge angles and energies (4MV (Blue), 8MV (Green), 15MV (Red)).

Table 1 Uncertainties of "*in vivo* Dosimetry" in function of treatment type.

Localization	Expected dose	Measured dose	Overall
Pelvis	X15: ± 0.92%	± 4.92%	± 5%
Breast	In X4: ± 1.1%	In X4: ± 6.01%	± 6.1%
	In X15: ± 0.92%	In X15: ± 7.22%	± 7.27%

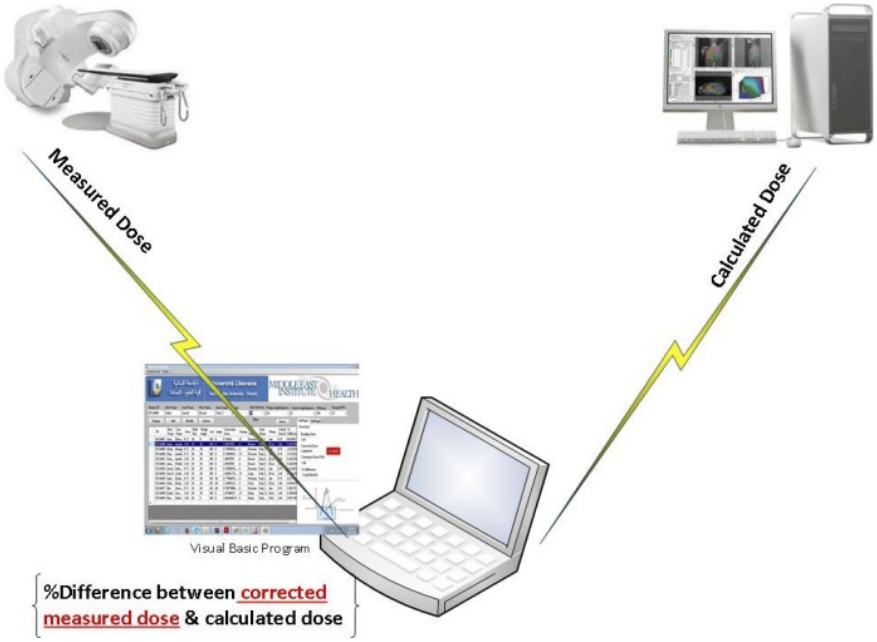

Fig. 5 Block diagram of the station with remote wireless control.

main program for receiving the data from the TPS, the diodes reading and processing these data so that the user compare directly the results and analyze them in an easy way;

(1) Database: The database is composed of two tables, the "Display" and "Correction Factors" tables which include the details information of the patient and the corrected dose (Figs. 6 and 7).

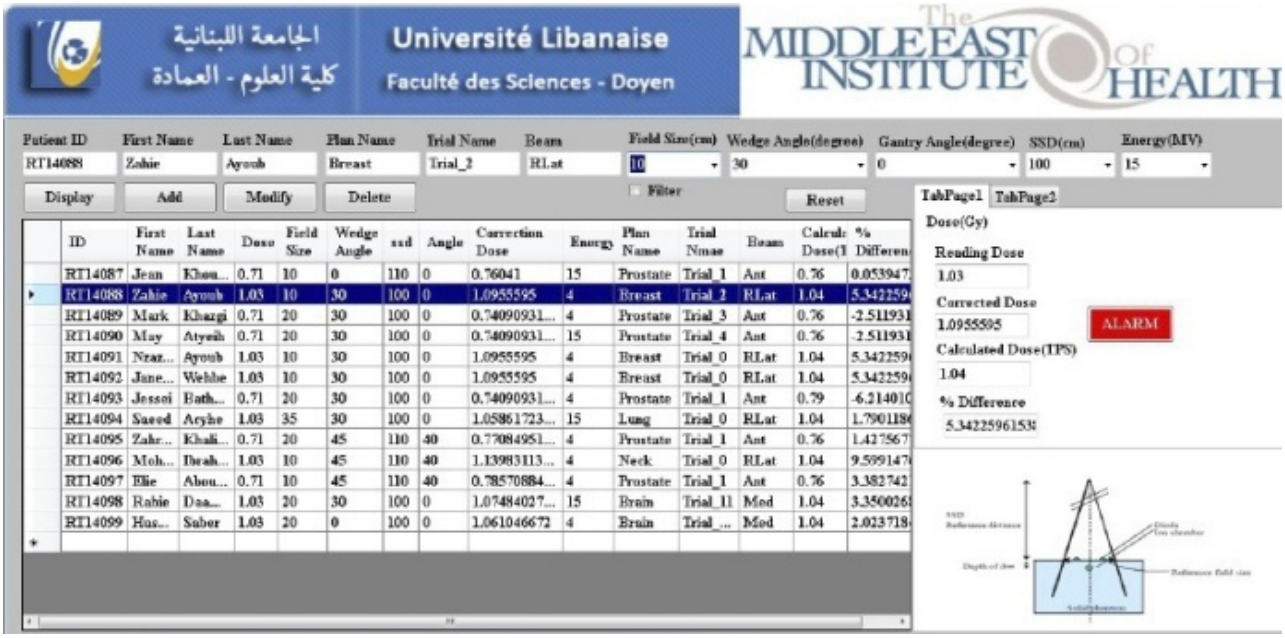

Fig. 6 Data base management system.

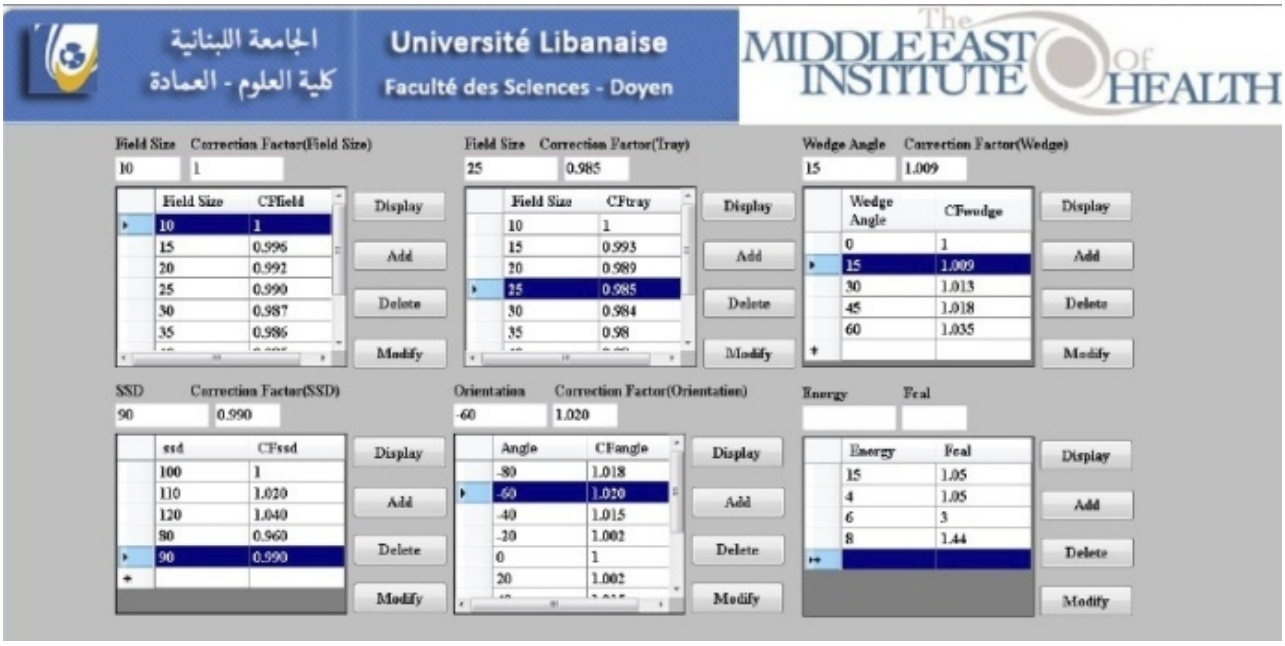

Fig. 7 Data base management system of the correction factors.

4.2 Purpose

The authors' purpose is to implement an "Embedded *In Vivo* Dosimetry System" that provides: speed of data processing and computerization of the process. In addition the system is able to alert the end user if any of the values exceed the threshold including the tolerance defined above.

5. Conclusion and Perspectives

The present study was interested in '*in vivo*' dosimetry by semiconductor detector. The purpose of *in vivo* dosimetry is error detection.

The present goal was to determine if:

- The difference obtained is a direct consequence of the uncertainties associated with the calculation and

measurement of the dose;

- The difference reflects although an error in the processing chain;

For this, the authors have established a methodology to assess and quantify the uncertainties involved in the measurement system: evaluation of uncertainties in:

- A simple geometric case;
- Theoretical clinical cases.

The authors determined and listed the uncertainties between the expected and measured dose for theoretical and clinical cases for pelvis and breast treatment. The tolerances range (± 5% for pelvis treatment, ± 6.1% for breast using a (4MV) beam and ± 7.27% for breast treatment using a (15MV) beam) are fixed.

For breast treatment the authors have proved that the ICRU 5% tolerance cannot be achieved in the present institution taking into account the complexity of the treatment and present materials and accessories (presence of wedge, beam angulations, SSD variation and incertitudes related to patient positioning). By the end of the present study the authors have developed an integrated monitoring system that offers accurate information about the dose received by patients.

In the future, it would be interesting to continue the following work by analyzing the results of measurements made on patients in order to correlate with the uncertainties determined by the present methodology.

References

[1] Mayles, W. P. M. 2007. "The Glasgow Incident a Physicist's Reflections." *Clin. Oncol.* 19: 47.

[2] Williams, M. V. 2007. "Radiotherapy Near Misses, Incidents and Errors: Radiotherapy Incident in Glasgow." *Clin. Oncol.* 19: 13.

[3] Derreumaux, S., Etard, C., Huet, C., Trompier, F., Clairand, I., and Bottollier-Depois, J.F. et al. 2008. "Lessons from Recent Accidents in Radiation Therapy in France." *Radiat. Prot. Dosim.* 131 (1): 130-5.

[4] International Commission on Radiological Protection, ICRP Publication 112, 2009. "Preventing Accidental Exposures from New External Beam Radiation Therapy Technologies." *Ann. ICRP* 39 (4): 186.