Iranian Journal of Medical Physics

ijmp.mums.ac.ir

Performances analysis of Sugar/EPR, Lithium Formate Monohydrate/EPR and Sulfamic acid/EPR dosimetry systems in evaluation of doses delivered during the prostate cancer treatment, using an anthropomorphic phantom

Fatna Zahiri [1*], Mohammed Mikou [1], Hanae El Gouach [2], Kamal Saidi [2, 3], Redouane El Baydaoui[3]

1. Hassan First University, Faculty of Science and Technology, Emerging Technologies Foresight Laboratory, B.P. 577, 26000 Settat, Morocco
2. Department of Radiotherapy, Sheikh Khalifa International University Hospital, BP 82403 Casa Oum Rabii, Hay Hassani Boulevard Mohamed Taieb Naciri, Casablanca, Morocco
3. Hassan First University, Higher Institute of Health Sciences, Laboratory Sciences and Engineering of Biomedicals Biophysics and Health, B.P. 555, 26000 Settat, Morocco

ARTICLE INFO

Article type:
Original Paper

Article history:
Received: Jan 26, 2024
Accepted: July 17, 2024

Keywords:
Sugar/EPR Dosimetry
Lithium Formate Monohydrate/EPR Dosimetry
Sulfamic Acid/EPR Dosimetry
Anthropomorphic Phantom
Prostate Cancer
Radiotherapy

ABSTRACT

Introduction: The aim of this work is to test the suitability of the three dosimetry systems: sugar/EPR (Electron Paramagnetic Resonance), lithium formate monohydrate/EPR (LFM/EPR) and sulfamic acid/EPR in the control and assessment of the dose delivered in tumor volume and surrounding organs during radiotherapy treatment of prostate cancer. Thus, the study proposes to compare the doses calculated by the treatment planning system (TPS) with the doses measured by the three dosimetry systems used, in order to verify their ability to evaluate the clinical doses administered.

Material and Methods: To perform this work, the various dosimeters studied were placed at the level of the tumor and the surrounding organs in a male anthropomorphic phantom. To simulate radiation therapy for prostate cancer, the phantom used was irradiated by 6 MV X-rays after careful implementation of a treatment plan for the determination and execution of the prescribed dose, using CT (Computed Tomography) imaging and TPS calculations.

Results: The irradiated dosimeters were analyzed by EPR and the determined doses were compared to the doses calculated by the TPS system. The results obtained show that the doses measured by the studied dosimetry systems are similar to calculated doses. The sugar/EPR system appears to be more accurate than the other two dosimetry systems.

Conclusion: The three dosimetry systems used show promise for applications as dosimeters in radiotherapy.

► *Please cite this article as:*
Zahiri F, Mikou M, El Gouach H, Saidi K, El Baydaoui R. Performances analysis of Sugar/EPR, Lithium Formate Monohydrate/EPR and Sulfamic acid/EPR dosimetry systems in evaluation of doses delivered during the prostate cancer treatment, using an anthropomorphic phantom. Iran J Med Phys 2025; 22: 120-129. 10.22038/ijmp.2025.77758.2368.

Introduction

To avoid the risk of radiological accidents, it is important to monitor and measure the effective dose of radiation delivered to the patient during a radiotherapy treatment. The delivered dose must not deviate significantly from the prescribed dose (less than 5%) (1). Accurate and reliable dosimeters are needed, that can be placed on the patient's skin surface at the beam entrance or at the beam exit to assess the effective dose delivered during treatment. For this purpose, several dosimetry systems have been used such as diode (2,3), MOSFET (Metal Oxide Semiconductor Field Effect Transistor) (4,5), TLD (Thermoluminescent Dosimeters) (6,7), OSL (Optically Stimulated Luminescence) (8) and dosimetric systems based on the EPR (Electron Paramagnetic Resonance) technique (9–12). The EPR is a non-destructive method; the dose can be re-read several times if necessary (13,14) with the possibility of measuring the cumulative dose using the same dosimeter during a radiotherapy treatment (15).

It is also interesting to verify in volume, the doses delivered to a tumor and the neighbouring organs during a radiotherapy treatment elaborated by a TPS (Treatment Planning System). The studies carried out in this context focus more specifically on the doses delivered to the tumour in volume. These include, for example, assessing doses delivered during Stereotactic radiosurgery (SRS) (16), verifying dose during total body irradiation (17), validating the accuracy of a commercial TPS in planning and

*Corresponding Author: Tel: +212605394321; Email: f.zahiri@uhp.ac.ma

delivering of dose painting by contours (DPBC) for advanced lung cancer compared to conventional treatment (18), measure and verify the total doses delivered by complex radiotherapy treatments (19), or demonstrate that dose painting by numbers (DPBN) can be delivered with high dosimetric accuracy to an anthropomorphic lung phantom (20). Our aim is to develop this dosimetry not only for tumours but also for organs at risk. In our work, we propose to study the dose distribution in volume during a treatment of prostate cancer, using a anthropomorphic phantom. For this fact, we used three dosimetric systems: sugar/EPR, LFM/EPR and sulfamic acid/EPR. These were placed inside the tissue equivalent phantom simulating the human body, which was then subjected to radiotherapy treatment. The dosimeters were then analyzed by EPR to measure the dose assigned in volume. Finally, the doses measured by the three dosimetry systems were compared with the doses calculated by the TPS. The choice of the three materials used is due to their dosimetric properties, characterized by their sensitivity to low doses of irradiation, the linearity of their calibration curve and their good stability during the storage period after irradiation (21–24). Thus, this work aims to analyze the feasibility of using the three dosimetric systems investigated in clinical dosimetry.

Materials and Methods

Dosimeters preparation

Table sugar (purchased from a local market, Cosumar of Casablanca, Morocco), LFM and sulfamic acid were purchased from Sigma-Aldrich. For each material, 58 samples of 80 mg were prepared (Figure 1 (a)). The samples were numbered; each number designates a location inside the phantom using a support with an orifice when the dosimeter is sectional-type inserted (Figure 1 (b)). The samples were protected from the effects of environmental factors.

Phantom used

The phantom used in this study is a CIRS ATOM® phantom series male phantom (adult male phantom Model 701-D), characterized by a height of 173 cm and a weight of 73 kg, designed to study organ dose, whole body effective dose and verification of therapeutic radiation dose delivery. It is a phantom with traditional 25 mm thick sections. The surfaces of the sections are extremely flat and smooth and do not require any special coating or treatment. This results in minimal interfaces between the sections when viewed in a scanning or projection X-ray machine. The following figure shows a real photo of the phantom used mounted to avoid errors in the movement of the sections (Figure 2 (a)), and a section that shows the positions where the dosimeters are placed (Figure 2 (b)).

Irradiation procedures

Irradiation for dosimetry curves*:* For the calibration curves, powder samples of 80 mg (of sugar, LFM and sulfamic acid) were prepared in the form of flat rectangles (Figure 1 (a)) and irradiated by X-6 photon beams produced in a linear accelerator "TrueBeam STx", installed at the Sheikh Khalifa University Hospital in Casablanca, Morocco, with doses ranging from 0 to 20 Gy. Irradiations were performed by placing the sample inside a PMMA phantom (Figure 3). To analyze the reproducibility of the results, for each irradiation dose and each material, four samples were irradiated for low doses (0 to 2 Gy) and two samples for high doses.

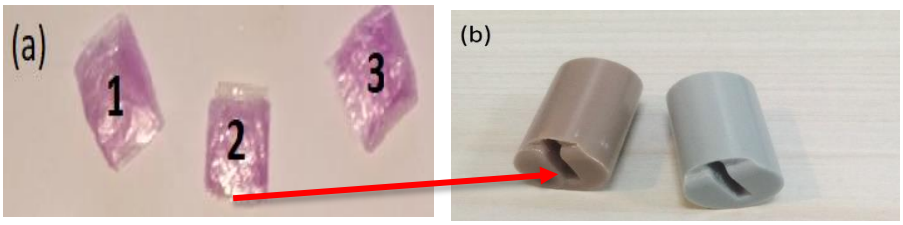

Figure 1. Prepared samples (a) and sample supports inserted in phantom (b).

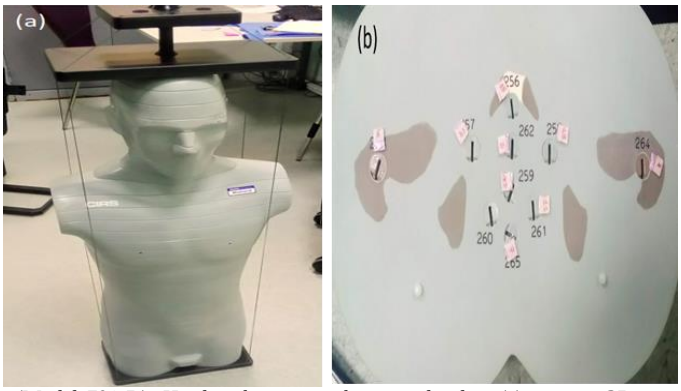

Figure 2. Adult ATOM phantoms (Model 701-D): Head with c-spine, thorax and pelvis (a); section 35, part of pelvis with the localization of samples (b).

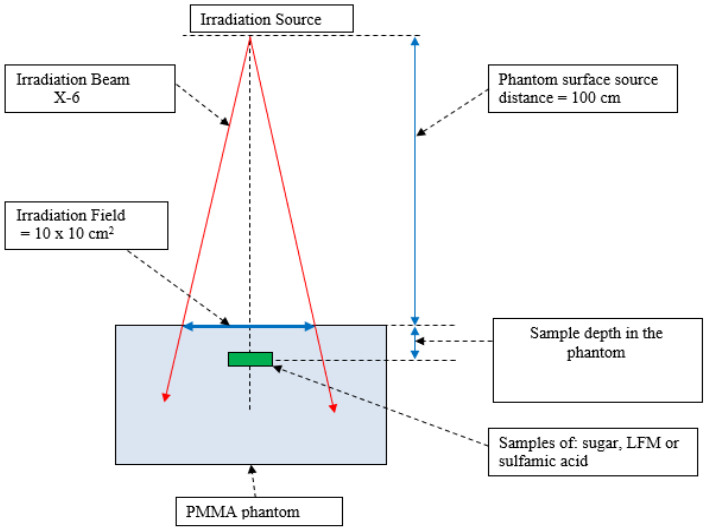

Figure 3. Irradiation Geometry by photon beams.

Before the irradiation (calibration curve samples or phantom), the verification of the absolute dose of the TrueBEAM STX linear accelerator is made using an ionization chamber: Semiflex 0.3 (S/N2184, Flow rate: 600 UM/Min). The calibration of the chamber is done according to the following references: a calibration factor of the detector ND,w = 5,361107 Gy/C, a beam quality of 60Co, a correction factor KD: 1.00 and an uncertainty of 1.1%.

ND,w: Calibration factor in terms of absorbed dose in water.

Phantom's irradiation

In this study, we used the 3D conformal radiotherapy (RC3D) technique with 4 conformal radiation fields (anterior, posterior, right lateral, left lateral), to simulate the treatment of a tumor localized in the prostate. To control and evaluate the absorbed dose, the dosimeters were placed in tumor and surrounding organs. The selected nominal treatment dose is 8.5 Gy. This relatively high dose offers the possibility to evaluate low absorbed doses outside the target volume; in particular in the organs at risk. For statistical evaluations and reproducibility analysis of results, three irradiation experiments were performed for each type of dosimeter under the same conditions.

Table 1. Acquisition parameters of CT scan images realized on the phantom

Parameter	Description
Type of acquisition	Helical Full (0.6 s)
SFOV	Wide
kV	120
mA	250
Cutting depth (mm)	2.5
Total acquisition time (s)	13.70
Number of images	161

Scanning

A 16-slice CT scan is performed on the phantom by a GE scanner, Discovery CT590 RT, and Optima CT580. It is a pelvic exam. The phantom is placed on the CT simulator table in the supine position, leaded registration points are placed on the images and thin CT slices are made, 0.6 mm in width. Table 1 shows the parameters of the scanner image acquisition protocol with their description.

Contouring

To know the dose delivered to the target volume and the healthy organs, the preliminary step to planning is the delineation of these volumes of interest performed by the physician on the CT images, allowing the construction of 3D volumes. The TPS is used to delineate the tumor and the organs to be protected using contouring tools. On the contouring station, the CT images of the phantom are imported and the volumes are delimited by drawing the target volume to be irradiated and the organs at risk to be spared. Figure 4 shows a pelvis CT image where all organs have been contoured with dosimeters placed in each organ.

Table 2 shows all irradiated organs with their volume and the number of inserted dosimeters.

Dosimetry

On the imported and profiled scanner images, our treatment ballistics are established on the TPS console. The dose calculations were performed by the anisotropic analytical algorithm (AAA, Eclipse version 13.3.35) with inhomogeneity correction used with a 2.5 mm grid for the dose calculation. The TPS calculations were validated during the commissioning phase (25), after which the linear accelerator was verified daily using Farmer ionization chambers (26). The dosimetry performed consisted of 4 fields on each side (anterior, posterior, right lateral and left lateral) by X-rays 6 MV and a prescribed dose of 8.5 Gy (Figure 5).

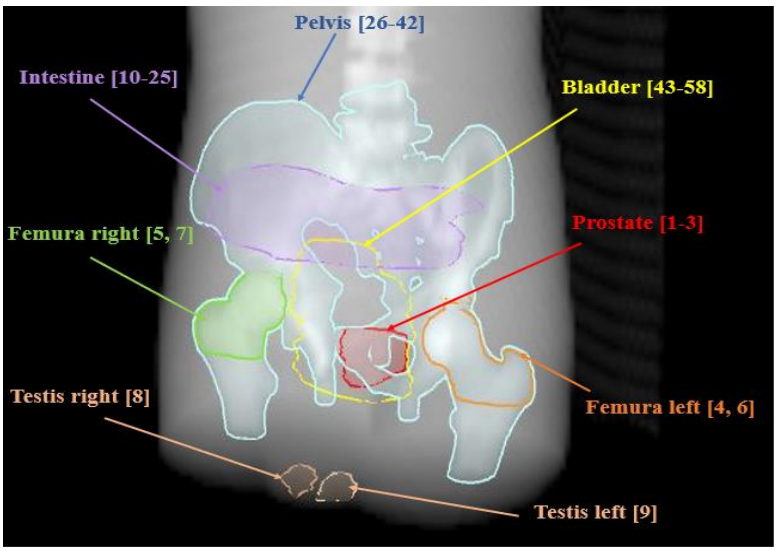

Figure 4. Contouring the target volume and organs at risk on a scanner image, the intervals give the numbers of the dosimeters located in each organ.

Table 2. Volume and dosimeters were inserted in each organ tested.

Organ	Volume (cm^3)	Number of dosimeters inserted
Prostate	40.1	3
Femura right	69.8	2
Femura left	80	2
Bladder	343.8	16
Testis right	3.5	1
Testis left	3.3	1
Intestine	410.7	16
Pelvis	954.7	17

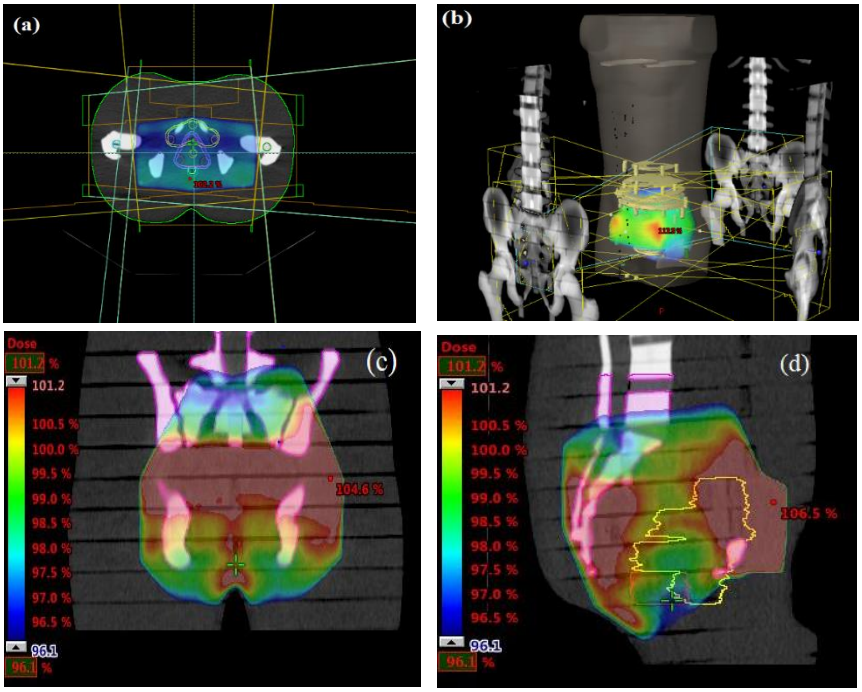

Figure 5. Scanner images imported into TPS: Beams delimiting the tumor (a), 3D Image (b), Frontal cut (c), Sagittal cut (d).

The dose of 8.5 Gy was normalized to the isocenter of the intersection of all fields. The total dose of 8.5 Gy was delivered in one session, at the end the dosimetry was validated.

Irradiation treatment

The phantom used contains orifices located at the different organs. Inside these holes, the samples from the different dosimeters are placed. Each sample is identified with a serial number then, the phantom is placed on the treatment table, under a "TrueBeam STx" linear accelerator. A quality control test of the linear accelerator dose stability was performed before irradiation. The alignment was done to the points already established in the scanner simulator using the IGRT onboard imaging system (CBCT and kV). The phantom set-up was reproduced in the same way as the dosimetric scanner. We recover the irradiated samples at the end of the session. The irradiations were done separately for each material.

EPR measurements

The EPR measurements were made using a spectrometer EPR "MS-400" Magnettech (Berlin, Germany) operating in X-band. Table 3 shows the EPR measurement parameters used. These parameters have been determined in previous work (21–23). A reference sample of 1,1-diphenyl-2-picrylhy- drazyl (DPPH) was used as a standard reference for calibration of the spectrometer before and after use.

Table 3. EPR measurement parameters.

Parameter	Optimal value
Amplitude modulation	0.5 mT
Microwave power	1mW
Number of scans	1-20 times
Sweep time	60 s
Time constant	0.1 ms
Spectrum resolution	4096 points
Room temperature	23 ± 1 ° C
Cavity temperature	30 ± 1 ° C

Four measurements were registered for each irradiated sample. We subtracted the residual signal intensity measured on the non-irradiated sample.

The weight was chosen as part of optimization and manufacturing of the small dosimeter. In this study, the weight is of the order of 80 mg for irradiation and 60 mg for EPR measurements. The samples were irradiated by doses ranging from 0 to 20 Gy. From the linear regression equations of each curve, we extracted the dose absorbed by each dosimeter placed in the phantom.

It is important to mention that the EPR intensity of residual signal, measured on the unirradiated sample, was subtracted from the value measured on each dosimeter before comparing it to the dosimetry curve. This was done to obtain the net dose absorbed by each dosimeter and make more accurate comparisons with the doses provided by the TPS.

Results

Dosimetry curves

EPR measurements were performed one day after irradiation with the optimal parameters presented in Table 3. Figure 6 shows the EPR spectra obtained for each material with a dose of 20 Gy. Table 4 shows the results obtained for these irradiations, it should be noted that before plotting the peak-to-peak (PP) intensities in this table, we subtracted the residual signal intensity measured on the unirradiated sample.

The PP values not reported in the table represent intensity values not accurately determined. They correspond to doses below the measurable threshold dose for the material considered (Sulfamic acid threshold dose: 0.25 Gy (23), LFM threshold dose: 0.55 Gy (22), Sugar threshold dose: 1.5 Gy (21).

RSD (Table 4) is the relative standard deviation, and is a measure of relative dispersion. In our study, RSD measures the relative deviation in % observed for four measurements made of each dose.

Figure 7 shows the response of each material (sugar, LFM and sulfamic acid) to different irradiation doses of X-rays 6 MV. The spectral analysis is performed using the PP method. The EPR response according to the dose for each material is linear with a correlation coefficient greater than 0.999.

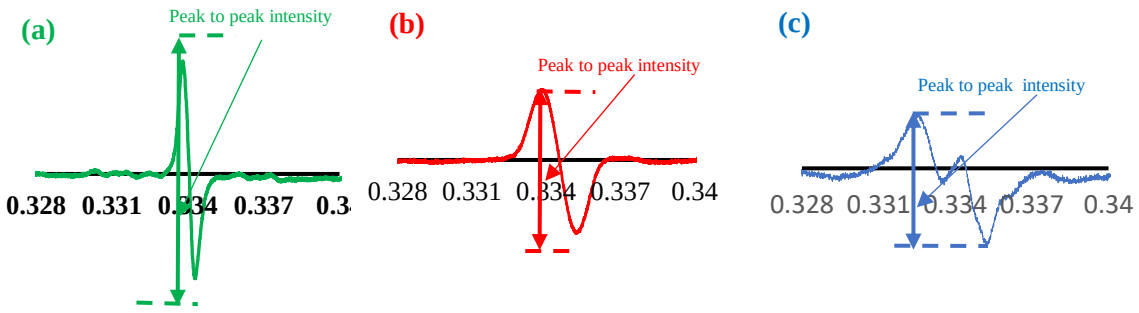

Figure 6. EPR spectra of the materials used irradiated by X-6MV rays with a dose of 20 Gy: sulfamic acid (a), LFM (b) and sugar (amplified by a factor of 2) (c).

Table 4. Numerical results of EPR measurements performed on material samples (sugar, LFM and sulfamic acid) irradiated by X-6MV rays with a dose range [0-20 Gy].

Dose (Gy)	EPR Intensity PP (a.u)								
	Sugar			LFM			Sulfamic acid		
	Mean (a.u)	Std. deviation	% RSD	Mean (a.u)	Std. deviation	% RSD	Mean (a.u)	Std. deviation	% RSD
0	-	-	-	-	-	-	-	-	-
0.25	-	-	-	-	-	-	229.38	15.43	6.72
0.5	-	-	-	-	-	-	339.14	14.89	3.10
1	-	-	-	420.34	9.68	2.30	670.58	11.50	1.42
1.5	165.63	6.76	4.083	436.30	16.15	3.70	1073.77	32.28	2.66
2	236.13	7.91	3.350	758.52	20.38	2.69	1419.56	22.99	1.47
2.5	365.28	13.51	3.700	1011.37	4.46	0.44	1864.75	35.77	1.78
4	619.20	3.81	0.617	1706.78	17.70	1.04	3119.26	94.51	2.90
6	883.60	34.27	3.879	2577.77	26.41	1.02	4456.84	130.88	2.85
10	1454.23	14.71	1.012	4042.42	64.85	1.60	7659.05	200.76	2.57
15	2257.61	58.42	2.588	6086.53	58.25	0.96	11128.03	94.98	0.84
20	3029.91	17.65	0.583	8081.82	32.89	0.41	14781.18	186.32	1.25

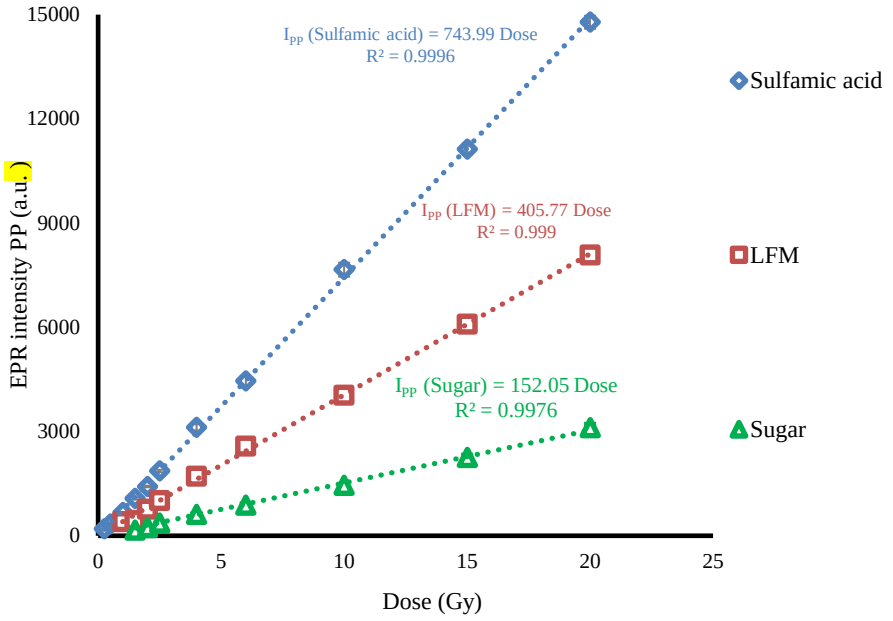

Figure 7. Calibration curves of the dosimetric systems used.

The dosimetry curve was established for each material used to extract the irradiation doses absorbed by that material. Thus, for the three dosimetric systems studied (sugar/EPR, LFM/EPR and sulfamic acid/EPR), the dosimetry curves were established, PP intensity of EPR measured spectrum was represented versus irradiation dose (Figure 7). For each material used, the irradiations performed for the establishment of the dosimetry curves were carried out on the same day and under the same conditions, as the irradiations elaborated on the phantom containing the samples (temperature, pressure, weight, shape, irradiating particle, irradiation energy).

An uncertainty budget was followed to estimate uncertainties regarding the doses extracted from the established dosimetry curves. Indeed, uncertainty is grouped into two categories (27). Type A dose uncertainties (assessed by statistical methods from a series of repeated observations (uA) and type B (assessed by non-statistical methods (uB), i.e., derived from the calibration provided by the manufacturer) are combined to estimate the total uncertainty of the dose assessed by the dosimeter. Various sources can contribute to the uncertainty in absorbed dose estimates, such as calibration of the dose rate by a reference dosimeter, the irradiation facility, post-radiation stability, environmental conditions, batch uniformity, EPR spectrometer, EPR sensitivity, calibration curve fit, sample positioning .... All components of uncertainty, whether Type A or Type B, are combined to estimate the overall uncertainty. The estimation of the uncertainty parameters is based on the methods described in the literature. Table 5 summarizes the parameter uncertainties for dose monitoring.

Table 5. Uncertainty budget associated with dose monitoring by dosimetric systems: Sugar/EPR, LFM/EPR, Sulfamic acid/EPR for a phantom simulating prostate cancer irradiated by X-6 MV with a dose of 8.5 Gy.

Uncertainty parameters	Type of uncertainty	Standard uncertainty %
Dose rate calibration by reference dosimeter[a] (U_{Cal})	B	1.10
Irradiation facility (U_{Irrad})	B	0.65
Sensitivity variation of EPR spectrometer (U_{Sen})	A	0.19
Reproducibility of EPR spectrometer (U_{Rep})	A	0.68
Batch uniformity (U_{Ba})	A	Sugar: 1.87 LFM: 1.49 Sulfamic acid: 1.88
Calibration curve fitting (U_{Fit})	A	Sugar: 0.85 LFM: 0.78 Sulfamic acid: 1.37
Temperature effect (U_{Tem})	A	Not evaluated and estimated negligible
Post-irradiation stability (U_{Stab})	A	Sugar: 0.04 LFM: 0.13 Sulfamic acid: 0.09
Humidity effect (U_{Hum})	A	Not evaluated and estimated negligible
Sample positioning (U_{Pos})	A	0.21

[a] as quoted from calibration certificate.

Table 6. Summary of the budget of uncertainty of each dosimetric system.

Dosimeter	Sugar/EPR	LFM/EPR	Sulfamic acid/EPR
Uc (1σ) %	2.54	2.24	2.75
Uc (2σ) %	5.09	4.48	5.51

The combined uncertainty (Uc), 1σ type was estimated using the following formula:

$$U_c = \sqrt{U_{Cal}^2 + U_{Irrad}^2 + U_{Sen}^2 + U_{Rep}^2 + U_{Ba}^2 + U_{Fit}^2 + U_{Hem}^2 + U_{Tem}^2 + U_{Stab}^2 + U_{Pos}^2} \quad (1)$$

The doses extrapolated from the calibration curves are evaluated with an error rate relative to the cited parameters. we represent the results of the uncertainty budget of each material in Table 6.

From the data in Table 6, the combined uncertainty (1σ) of the dose is found to be approximately 2.54 % for sugar, 2.24 % for LFM and 2.75 % for sulfamic acid. The overall uncertainty (the combined standard uncertainty multiplied by a coverage factor of 2, σ=2), was found to be 5.09 % (sugar), 4.48 % (LFM) and 5.51 % (sulfamic acid). These uncertainty values prove the validity of the dosimeters prepared for application in the verification and quality control of the radiation therapy dose especially in the case of prostate cancer treatment. These uncertainties can be reduced by manufacturing calibrated pellets in weight and volume.

Evaluation of the absorbed dose by the employed dosimetric systems and comparison with the TPS data

Table 7 shows the results of dosimetric measurements using the three types of dosimeters used, incised into the phantom at the level of the prostate tumor and neighbouring organs; and the results of the calculations made by the TPS system.

For each type of dosimeter, three phantom irradiation experiments followed by EPR measurements were performed. The estimate dose value shown in the table is the mean value for the three experiments and the deviation shown is the percentage difference between the dosimeter measurements and the values given by the TPS system. The dose values not displayed in the table correspond to the values below the threshold measurable by the dosimeter (threshold values represented above). Following the treatment plan implemented, we find that the prostate, pelvis and bladder received almost the nominal dose of 8.5 Gy, as well as part of the intestines. A part of the femur received a relatively high dose of 5.3 Gy and another part received a low dose. The testicles received a relatively low dose.

Table 7. Doses measured by the sugar/EPR, LFM/EPR and sulfamic Acid/EPR dosimetry systems compared to those calculated by the TPS system.

Results of EPR measurements (Peak-to-peak)								
Organ	Dosimeter ID	TPS	Sugar		LFM		Sulfamic Acid	
		Mean_Dose (Gy)	Mean_Dose (Gy)	% dose difference (TPS - Sugar)	Mean_Dose (Gy)	% dose difference (TPS-LFM)	Mean_Dose (Gy)	% dose difference (TPS_Sulfamic acid)
Prostate	1	8.4	8.41	1.54	8.35	0.73	8.46	2.48
	2	8.4	8.38	0.33	8.46	0.71	8.42	0.97
	3	8.3	8.37	1.54	8.35	1.55	8.01	3.49
Femura	4	5.3	5.38	1.59	5.34	2.10	5.36	3.91
	5	5.3	5.37	1.25	5.34	0.74	5.44	2.73
	6	0.6	-	-	0.59	2.39	0.60	3.42
	7	0.5	-	-	-	-	0.59	19.34
Testes	8	1.5	1.43	4.38	1.44	4.09	1.34	0.93
	9	1.4	-	-	1.33	5.32	1.38	0.75
Intestine	10	0.5	-	-	-	-	0.55	7.48
	11	0.5	-	-	-	-	0.56	12.56
	12	0.5	-	-	-	-	0.49	7.53
	13	0.6	-	-	0.64	6.56	0.57	6.58
	14	4.6	4.58	3.60	4.10	10.94	4.24	7.85
	15	6	5.82	2.99	5.82	3.05	5.66	3.01
	16	4.8	4.73	1.36	4.74	4.49	4.60	4.21
	17	6.6	6.52	1.23	6.48	3.45	6.39	3.21
	18	4.9	4.86	0.95	4.93	0.70	4.98	3.00
	19	8.5	8.33	2.02	8.51	1.49	8.53	2.70
	20	8.9	8.97	0.91	8.81	1.43	8.56	3.85
	21	7.9	8.00	3.14	7.88	2.94	7.81	2.12
	22	8.5	8.39	1.29	8.58	1.53	8.47	0.81
	23	8.5	8.64	3.12	8.36	2.05	8.65	2.81
	24	8.7	8.76	1.60	8.65	1.01	8.49	2.44
	25	8.6	8.67	0.89	8.41	2.22	8.59	2.00
Pelvis	26	5.6	5.58	0.41	5.73	2.34	5.56	1.78
	27	8.5	8.57	2.69	8.42	1.04	8.36	1.73
	28	6	5.98	2.20	6.02	1.47	6.07	1.10
	29	5.6	5.61	1.91	5.66	1.15	5.69	7.70
	30	5.6	5.58	1.56	5.63	0.82	5.76	2.83
	31	8.6	8.69	2.68	8.34	3.02	8.45	0.44
	32	8.5	8.36	1.69	8.47	1.91	8.66	3.72
	33	8.7	8.77	0.85	8.64	2.33	8.47	1.07
	34	8.5	8.35	1.73	8.45	1.05	8.49	0.99
	35	8.7	8.73	3.40	8.64	0.90	8.85	2.95
	36	8.6	8.75	1.73	8.72	2.55	8.83	3.91
	37	8.6	8.60	0.93	8.64	0.82	8.78	2.07
	38	8.6	8.71	1.23	8.63	1.28	8.79	3.01
	39	8.6	8.82	2.51	8.51	2.29	8.57	3.07
	40	8.5	8.41	1.93	8.43	1.37	8.74	2.79
	41	8.1	8.05	1.26	8.01	1.14	8.14	0.70
	42	8.1	8.17	0.87	7.96	1.69	8.09	7.90
Bladder	43	8.8	8.84	2.33	8.76	1.31	8.99	3.71
	44	8.8	8.88	2.33	8.69	1.80	8.99	2.19
	45	8.7	8.63	0.85	8.71	1.59	8.71	4.43
	46	8.8	8.78	1.52	8.64	1.77	8.77	0.97
	47	8.8	8.92	1.31	8.78	1.10	8.96	2.90
	48	8.7	8.82	2.66	8.64	0.79	8.59	1.29
	49	8.5	8.38	1.45	8.48	1.54	8.57	4.11
	50	8.6	8.71	1.26	8.60	1.74	8.62	1.29
	51	8.6	8.68	1.87	8.73	1.51	9.23	6.61
	52	8.4	8.39	0.81	8.44	2.61	8.43	2.35
	53	8.5	8.61	2.83	8.58	0.96	8.88	5.99
	54	8.4	8.42	1.47	8.43	0.52	8.75	3.69
	55	8.4	8.44	1.47	8.44	2.41	8.87	5.62
	56	8.2	8.18	1.25	8.25	2.56	8.23	1.11
	57	8.2	8.25	1.07	8.25	1.70	8.31	2.25
	58	8.4	8.33	2.07	8.43	1.05	8.30	0.96

Discussion

Considering the percentage difference between the dosimetric measurements and the TPS calculations, we can see that the results are relatively comparable, both in terms of the dose delivered to the tumor and the dose received by the neighbouring organs.

Some dosimeters give doses that deviate significantly from the TPS doses. This deviation is possibly due to the position and geometry of the irradiated sample, where part of the sample may be placed in a border zone between volumes irradiated with different doses.

From the results of this table and according to the % difference between the TPS dose and the dose calculated by each dosimetric system, we can also conclude that:

- For the sugar/EPR system:

100 % of measurements are below 5 % and 91 % are below 3 %.

- For the LFM/EPR system:

95 % of the measurements are below 5 % and 86 % are below 3 %.

- For the sulfamic acid/EPR system:

81 % of measurements are below 5 % and 53 % are less than 3 %.

The sugar/EPR system has better accuracy than the LFM/ EPR system, which is more accurate than the sulfamic acid/ EPR system. This accuracy is undoubtedly due to the stability of free radicals during the storage period

In order to compare our work with similar previous studies, we noted that Waldeland et al conducted Stereotactic radiosurgery Stereotactic radiosurgery (SRS) dosimetry using Lithium Formate EPR dosimeters, with a deviation of 1.7 % for a dose of 15 Gy (16). Schaeken et al verified a total body irradiation protocol using Alanine/EPR dosimetry in an anthropomorphic phantom with an uncertainty of 0.6 % for an administered dose of 10 Gy (17). Knudtsen et al used the Alanine/EPR dosimetry system to validate the dose painting technique for lung tumors (18). Höfel et al used Alanine/EPR and LFM/EPR for measuring and verifying the total doses delivered during complex IMRT treatments (19). Papoutsis et al evaluated the dosimetric accuracy of dose painting by numbers (DPBN) based on positron emission tomography using the alanine/EPR system (20).

Our study analysed the performance of three dosimeter systems: Sugar/EPR, Lithium Formate Monohydrate/EPR and Sulfamic acid/EPR, in assessing volume doses during radiotherapy treatment for prostate cancer. The aim of this study is not only to verify the dose delivered to the tumour, but also to assess the doses absorbed by the surrounding organs. This presents a number of difficulties in estimating the low doses received by these organs. The results showed the high sensitivity of the systems used, of the order of 0.25 Gy for Sulfamic acid and the good accuracy, in particular in the case of Sugar/EPR system. The doses obtained by the three systems are comparable to those of TPS, with a deviation of less than 5 % for low doses (of the order of 0.5 – 0.25 Gy) administered to organs at risk.

Most of the similar studies to our work have focused on the relatively high doses attributed to tumours. The majority of these studies have used particularly heavy and high-range EPR spectrometers, which could explain the level of precision obtained. In the case of our study, the doses less than 0.25 Gy are measured with resonable accuracy, using a small-range portable EPR spectrometer, which offers the potential for application of our systems in clinical dosimetry.

Conclusion

Thus, this study led to the following results:

- ✓ Possibility of measuring the dose assigned in volume to a tumor and neighbouring organs during radiotherapy treatment of prostate cancer. This dose measured can be as low as 0.25 Gy.
- ✓ The ability of table sugar, LFM and sulfamic acid to be used in the assessment of administered doses, based on the measurable threshold dose for each material.
- ✓ The analysis of the deviation between the dose values calculated by the TPS system and the doses measured by the three materials revealed that this deviation does not exceed 5% in the case of more than 80% of the dosimeters analyzed. Table sugar appears to be more accurate, with 100% of the samples analyzed showing a deviation of less than 5%.
- ✓ Our study has the advantage of proving that it is possible, using a portable, short-range EPR spectrometer, to carry out clinical dosimetry with reasonably acceptable accuracy.

Finally, the sugar/EPR, LFM/EPR and sulfamic acid/EPR dosimetry systems have the capacity to control and verify the prescribed doses in volume, during a radiotherapy treatment.

Acknowledgment

We wish to thank Sheikh Khalifa International University Hospital in Casablanca-Morocco for letting us use their accelerator to irradiate the phantom several times. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

1. ICRU Report 24. Determination of absorbed dose in a patient irradiated by beams of X or gamma rays in radiotherapy procedures. 1976.
2. Della Atuwo-Ampoh V, Naab Manson E, Schandorf C, Nii Tagoe S, Addison EK, 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;16:329–35.
3. Marzuki R, Rahman AA, Mustafa IS, Shabandi AN. Diode Dosimetric Characteristics Assessment for In-Vivo Dosimetry in Radiotherapy Treatment. J Phys Conf Ser. 2018;1083(1).

4. Gopiraj A, Billimagga RS, Ramasubramanian V. Performance characteristics and commissioning of MOSFET as an in-vivo dosimeter for high energy photon external beam radiation therapy. Reports Pract Oncol Radiother. 2008;13(3):114–25: http://dx.doi.org/10.1016/S1507-1367(10)60001-6
5. Won Y, Kim J, Kwon K, Kim S. Application of Patient-Customized Cast Type M3 Wax Bolus using a 3D printing for Photon Beam Radiation Therapy in Patients with Scalp Malignant Tumor. Iran J Med Phys. 2020;17(6):428–34.
6. Costa AM, Barbi GL, Bertucci EC, Ferreira H, Simone Z, Colenci B, et al. In vivo dosimetry with thermoluminescent dosimeters in external photon beam radiotherapy. Appl Radiat Isot. 2010;68(4–5):760–2: http://dx.doi.org/10.1016/j.apradiso.2009.09.039
7. Baradaran S, Taheri M, Moslehi A. Comparison and Correction of Thermo-Luminescent Responses in Different Neutron Fields. Iran J Med Phys. 2021;18(2):84–8.
8. Yukihara EG, Mckeever SWS, Akselrod MS. State of art : Optically stimulated luminescence dosimetry e Frontiers of future research. Radiat Meas. 2014;71:15–24: http://dx.doi.org/10.1016/j.radmeas.2014.03.023
9. Marrale M, Longo A, Russo G, Casarino C, Candiano G, Gallo S, et al. Dosimetry for electron Intra-Operative RadioTherapy: Comparison of output factors obtained through alanine/EPR pellets, ionization chamber and Monte Carlo-GEANT4 simulations for IORT mobile dedicate accelerator. Nucl Instruments Methods Phys Res Sect B Beam Interact with Mater Atoms. 2015;358:52–8: http://dx.doi.org/10.1016/j.nimb.2015.05.022
10. Rushdi MAH, Abdel-Fattah AA, Soliman YS. Physico-chemical studies for strontium sulfate radiation dosimeter. J Radiat Res Appl Sci. 2015;8(2):221–5: http://dx.doi.org/10.1016/j.jrras.2015.01.006
11. Gallo S, Iacoviello G, Panzeca S, Veronese I, Bartolotta A, Dondi D, et al. Characterization of phenolic pellets for ESR dosimetry in photon beam radiotherapy. Radiat Environ Biophys. 2017;56(4):471–80.
12. Aboelezz E, De Angelis C, Fattibene P. A study on energy dependence of nano barium sulfate powder using the EPR technique in photon, electron and proton beams. Meas J Int Meas Confed. 2021;175(March):109108: https://doi.org/10.1016/j.measurement.2021.109108
13. Nagy V. Accuracy considerations in EPR dosimetry. Appl Radiat Isot. 2000;52(5):1039–50.
14. Regulla DF. ESR spectrometry: A future-oriented tool for dosimetry and dating. In: Applied Radiation and Isotopes. Elsevier Ltd; 2005. p. 117–27.
15. Belahmar A, Mikou M, Hoehr C, El Ghalmi M. Cumulative dose experiments on Lithium formate monohydrate as an EPR-dosimeter for use in different radiation therapy scenarios. Nucl Instruments Methods Phys Res Sect B Beam Interact with Mater Atoms. 2022;532:1–6: https://doi.org/10.1016/j.nimb.2022.10.001
16. Einar Waldeland, Magnus H¨orling, Eli Olaug Hole ES and EM. Dosimetry of stereotactic radiosurgery using lithium formate EPR dosimeters. Phys Med Biol. 2010;55(8):2307–16.
17. Schaeken, Lelie, Meijnders and D. Van den Weyngaert, Janssens V. Alanine/EPR dosimetry applied to the verification of a total body irradiation protocol and treatment planning dose calculation using a humanoid phantom. Med Phys. 2010;37(12):6292–9.
18. Knudtsen IS, Svestad JG, Skaug Sande EP, Rekstad BL, Rødal J, Van Elmpt W, et al. Validation of dose painting of lung tumours using alanine/EPR dosimetry. Phys Med Biol. 2016;61(6):2243–54.
19. Höfel S, Fix MK, Drescher M, Zwicker F. Suitability of superficial electron paramagnetic resonance dosimetry for in vivo measurement and verification of cumulative total doses during IMRT: A proof of principle. Z Med Phys. 2021;31(4):365–77: https://doi.org/10.1016/j.zemedi.2021.03.006
20. Papoutsis I, Skjei Knudtsen I, Peter Skaug Sande E, Louni Rekstad B, Öllers M, van Elmpt W, et al. Positron emission tomography guided dose painting by numbers of lung cancer: Alanine dosimetry in an anthropomorphic phantom. Phys Imaging Radiat Oncol. 2022;21(September 2021):101–7.
21. Mikou M, Ghosne N, El Baydaoui R, Zirari Z, Kuntz F. Performance characteristics of the EPR dosimetry system with table sugar in radiotherapy applications. Appl Radiat Isot. 2015;99:1–4.
22. Belahmar A, Mikou M, El Ghalmi M. Analysis by EPR measurements and spectral deconvolution of the dosimetric properties of lithium formate monohydrate. Nucl Instruments Methods Phys Res Sect B Beam Interact with Mater Atoms. 2018 Sep 15;431:19–24.
23. Zahiri F, Gouache H El, Mikou M, Hoehr C, Saidi K. EPR analysis of the dosimetric properties of sulfamic acid irradiated by different ionizing radiations for radiotherapy and hadrontherapy applications. Nucl Instruments Methods Phys Res Sect B Beam Interact with Mater Atoms. 2021;506:23–31: https://doi.org/10.1016/j.nimb.2021.08.010
24. Zirari Z, Belahmar A, Mikou M, Hoehr C. Dosimetric and spectroscopic study of table sugar irradiated by X-ray and accelerated protons for therapeutic applications. Radiat Phys Chem. 2023;203(PA):110621: https://doi.org/10.1016/j.radphyschem.2022.110621
25. IAEA-TECDOC-1540. Specification and Acceptance Testing of Radiotherapy Treatment Planning Systems. 2007;1–68.
26. IAEA TRS-398. Absorbed Dose Determination in External Beam Radiotherapy. An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water. 2000;1–229.
27. Taylor, Barry N, Kuyatt CE. NIST Technical Note 1297 Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results. Technology. 1994.