ASSESSMENT OF A NEW DOSIMETER "SUGAR/EPR" RESPONSE DEPENDING ON THE DELIVERED DOSE BY A BEAM USED IN RADIOTHERAPY

N. Ghosne[1,2,4,5,7*], M. Mikou[2], A. Fahli[3], A. Benider[4], M. Moussetad[5], Aziz Boudlal[6]

[1] *Institut supérieur des professions infirmières et techniques de santé «ISPITS», Casablanca, Maroc*
[2] *Laboratoire d'Analyse des Systèmes et de Traitement de l'Information, Equipe : Spectroscopie et dosimétrie, Université Hassan 1er, Faculté des Sciences et Techniques, Settat, Maroc*
[3] *Université Hassan 1er Settat, Maroc*
[4] *Centre Med VI pour le traitement des cancers, Centre Hospitalier Universitaire Ibn Rochd, Casablanca–Maroc*
[5] *Laboratoire d'ingénierie et matériaux «LIMAT» Université Hassan II–Mohammedia, Faculté des Sciences, Ben M'sick, Casablanca, Maroc*
[6] *Faculté des Lettres et des Sciences Humaines, Ben M'sick Université Hassan II, Casablanca, Maroc*
[7] *GIDS–SE/ENS/LAPSTICE Université Hassan I, Faculté des Sciences, Ben M?'ick, Casablanca, Maroc*

*Corresponding author:
E–mail: nghosne@yahoo.com
Mobile: 00212664923298

Abstract: Radiotherapy is the treatment of cancers using ionizing radiations. Its goal is to sterilize cancerous tumours without overdosing the surrounding healthy tissue. Its success is based on precision during all stages of treatment especially through the dosimetry which is aunique means to measure the delivered dose to the patients. The precision and the quality of the dosimetric measurements are based on the use of a reliable and accurate dosimeter. The aim of our work was to highlight the dosimetric properties of the new dosimetric system "sugar/EPR" irradiated by a X18MV photon beam from a linear accelerator "Clinac 2100C" and analysed by EPR spectrometer in order to be used in radiotherapy. The study includes the phases of identification the EPR spectrum produced by the irradiation of sugar and the determination of the sugar/EPR response depending on the delivered doses, its calibration curve, its sensitivity and its limit of detection with respect to X18MV photons. The obtained results were important and corresponded with the literature showing the potential of the dosimetric system "sugar/EPR" asa promising treatmentin radiotherapy, and finally, we were able to conclude that it could be used as an alternative to enhance the accuracy of dosimetry in external radiotherapy.

Key words: Sugar, EPR spectrometry, dosimetry, X18MV photon, radiotherapy.

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Introduction

Cancer has become the second leading cause of death worldwide after cardiovascular diseases. Radiotherapy is the most widespread cancer treatment. However, it is potentially harmful with several sources of error, which may increase the uncertainty of the delivered dose to the patient to unacceptable values that could be the cause of serious harmif there is a substantial difference between the prescribed and delivered doses that may be overdosed (healthy tissues) or underdosed (tumour). The complexity of this treatment is basedon the new developing technologies, in addition to the serious adverse situations identified in recent years, and has prompted regulatory authorities to strengthen the quality and safety requirements in this specialty, including reliable control of delivered doses to patients. It is therefore essential to have a reliable and accurate dosimeter to measure the dose. Currently, several dosimeters are used.The most widely used are the ionization chamber and the semiconductors. Those are reliable and accurate though they present some disadvantages, namely their excessively high price, their fragility, and their periodic calibration which must be done in a licensed primary or secondary dosimetry laboratory. All of these reasons were compelling enough for us to undertake this research and develop a new dosimeter which is as reliable, accurate, and simple to use, and it could be cheaper than the previous ones. In this research, we tried to develop a new dosimetric system "sugar/EPR".

The choice of sugar was not done haphazardly because in addition to be non-toxic, available, inexpensive, and easy to prepare, sugar has been used in extensive academic studies published in recent years [1–9]. The purpose of this research was to study the dosimetric properties of sugar irradiated by a X18MV and analyse by electronic paramagnetic resonance "EPR" spectrometry. The studies carried out were:

- Identifying the EPR spectrum produced by the irradiation of sugar;
- Exploring the response of sugar/EPR based on the delivered doses;
- Establishing sugar/EPR is calibration curve;
- Determining the sensitivity and the limit of detection of "sugar/EPR" with respect to X18MV photons.

Materials and methods

1–Preparation of the sugar samples:

For the various studies conducted, we used an uncontaminated semolina sugar sold in the Moroccan market. The term "sugar" is conventionally used to describe mono and disaccharides, as well as derivatives of monosaccharides [10]. Sugar is a sucrose molecule which is a diholoside disaccharide made up of glucose and fructose. Its chemical formula is $C_{12}H_{22}0_{11}$.

The weight of each irradiated sample was 850 mg, whereas that of the analysed samples by EPR spectrometry was 200 mg. Indeed; this difference in weights is due to:

- For each irradiated sample and for each irradiation dose, several EPR analyses were carried out;
- The tube supporting the sample to be analysed is very thin and could not contain the entire irradiated sample.

To eliminate the parasitic signal which can impair the sugar/EPR response and decrease the accuracy of the dosimetric measurements, it was necessary to know the non–irradiated sugar signal. To get an idea about the RPE signal of non–irradiated sugar, we analysed non–irradiated samples. The obtained signal was not discernible from noise (Figure 1). This signal may be due to a very low concentration of free radicals created during the manufacturing process of the sugar or simply may be due to the background noise of the resonant cavity during the EPR analysis. This signal of non-irradiated samples is called "white signal" [11] and it?s considered as a parasite signal.

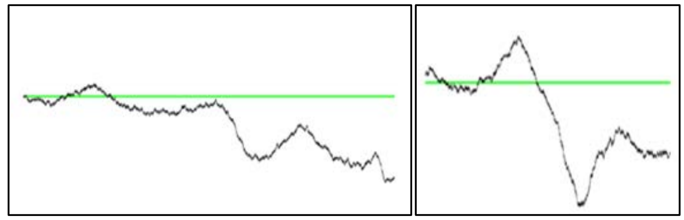

Fig. 1: Sugar/EPR spectra of both non irradiated sample (left) and irradiated sample with 2Gy (right).

2–Irradiation of the sugar's samples:

The irradiation of the sugar samples was carried out with a "Clinac 2100c" linear accelerator of particles installed at Mohammed VI centre for the treatment of cancers at Ibn Rochd University Hospital Centre in Casablanca, Morocco (Figure 2).

Fig. 2: "Clinac 2100c" linear accelerator used irradiation of the sugar samples.

To be similar to the human body, dosimetric acquisitions are carried out in a water equivalent medium [1]. The samples were irradiated on a perpendicular surface to the beam axis, inside a solid water equivalent phantom of polymethylmethacrylate "PMMA" under the same climatic conditions of clinical irradiation (ambient temperature, pressure and humidity). The samples were placed between the plates of that phantom at a depth of 2.7 cm, corresponding to the maximum depth dose of the used beam.

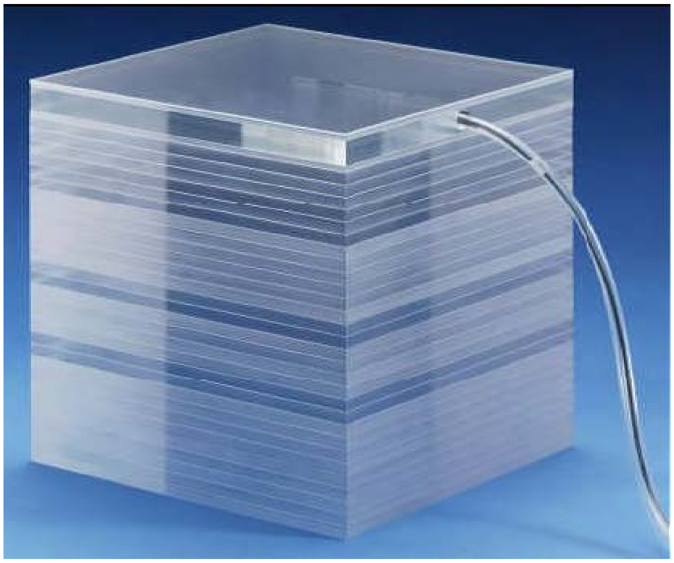

Fig. 3: "PMMA" solid water for equivalent phantom.

3–EPR analysis device:

The EPR analysis of irradiated sugar samples was undertaken using an MS300 EPR spectrometer from Magnettech, Berlin, Germany, installed at the AERIAL Technology Resource Center in Strasbourg, France.

The adopted parameters during all the EPR analyses were are as follows:

- Temperature: 20–22°C;
- Moisture content: 30%;
- Swept magnetic field is centred on $B_0 = 3358$G;
- Sweep width: 200G;
- Modulation of the magnetic field: 5000mG;
- Microwave frequency: 9.8GHZ;
- Time constant: 20.5ms;
- Scan time: 12s to 20s;
- Measurement resolution: 4096;
- Number of scans: 2 to 15;
- Excitation power: 10mW;
- Amplifier gain?s value: 200dB;
- Mass of the sample: 200mg;
- Size of the sugar grains: greater than 180μm

4–Studies carried out:

During these studies 18 samples of sugar were irradiated atthe following doses: 2Gy; 3Gy; 5Gy; 10Gy; 20Gy; 40Gy; 50Gy; 60Gy; and 80Gy. In order to test the reproducibility of the sugar/EPR response and to define the precision of the measurements, two samples weighing 850mg each were simultaneously irradiated for each given dose and were placed at the geometric centre of the irradiation field whose dimensions were $(10 \times 10)cm^2$, at a distance of 100cm from the source.

The aims of this study were:

- Identifying the EPR spectrum produced by the irradiation of sugar;
- Exploring the response of sugar/EPR based on the delivered doses;
- Establishing calibration curve for the "sugar/EPR";
- Determining its sensitivity with respect to 18MV X photons;
- Determining its limit of detection with respect to 18MV X photons.

Presentation, analysis and discussion of the results

We present in this section the obtained for the X18MV beam dosimetry using the sugar/EPR system. We will analyse both qualitatively and quantitatively the different EPR spectra of irradiated sugar with X18MV photons according to the conditions of the study carried out, in order to determine the dosimetric characteristics of "sugar/EPR" system.

1–Sugar/EPR response and EPR spectra depending on the dose:

Samples irradiated with doses [2–80 Gy] were analysed by EPR spectrometry. The objective was to determine the response based on the delivered doses during the irradiation, define its sensitivity, deduce its limit of detection; and establish its calibration curve depending on the dose.

The EPR spectrometry analysis of irradiated sugar samples with doses ranging from 2Gy to 80Gy yielded EPR spectra for each irradiation dose as shown in figure 4.

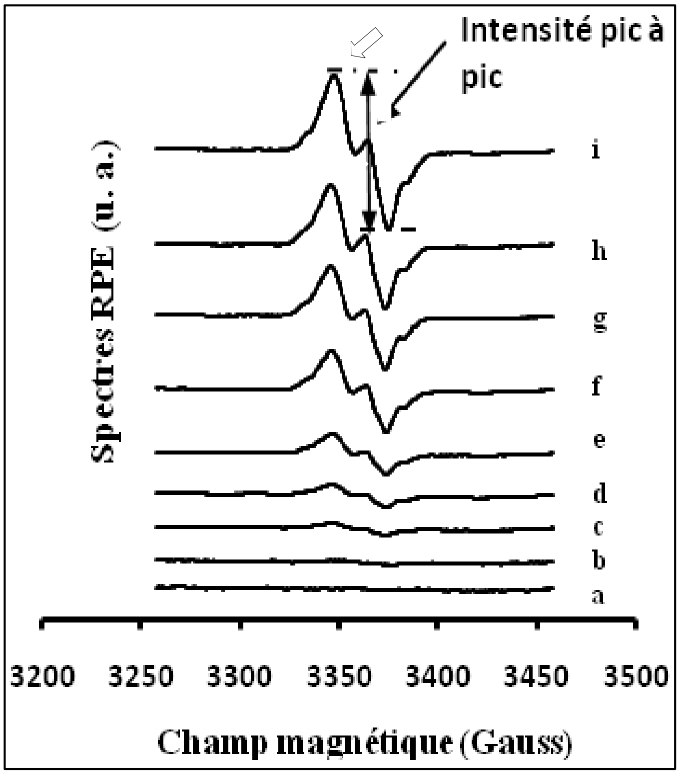

Fig. 4: EPR spectra of irradiated sugar by different dose, a: 0Gy; b: 2Gy; c: 5Gy; d: 10Gy; e: 20Gy; f: 40Gy; g: 50Gy: h: 60Gy; i: 80Gy.

We notice that the shape remains invariant despite the dose variation, whereas the amplitude increases steadily based on this dose. The intensive growth is caused by irradiation which leads to the creation of the free radicals whose concentration increases regularly based on the dose. We also notice that it was difficult to perform accurate EPR measurements for irradiated samples with 2Gy and 3 Gy which can be explained by the following reasons:

- The possibility of a small amount of free radicals in the collected fraction below the detection threshold of the spectrometer used;
- The spectrometer used is not sensitive enough to detect free radicals produced by low doses.

However, starting from 5Gy, EPR measurements were performed with a standard deviation less than 3% (Table 1), that represents a good reproducibility of the obtained results.

Table 1: Numerical values of the results of the EPR measurements depending on the dose.

Dose (Gy)	Peak to peak intensity of EPR signal (arbitrary unit)	Type difference	Error percentage (%)
2	1421	24,04	–
3	1847	107,00	5,79
5	3126,5	31,82	1,02
10	5571,25	203,08	2,65
20	10426,5	111,48	1,07
40	20392,75	324,91	1,59
50	25799,5	502,05	1,95
60	30948	196,59	0,64
80	40595,75	1000,65	2,46

2–Sugar/EPR is calibration curve:

The obtained results were used to draw the sugar calibration curve which represents the variation of the EPR signal peak–to–peak intensity based on the dose (Figure 5). It looks like a line whose equation is: $I = aD+b$, where: I is the intensity of the signal, D is the irradiation dose, a and b are constants to deduce directly from the curve. The curve also adjusts the experimental points with a correlation rate close to 1. The obtained curve will be used to determine the irradiation dose for any obtained EPR signal peak–to–peak intensity.

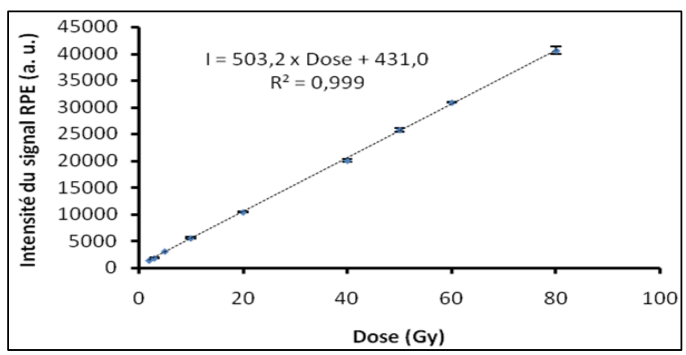

Fig. 5: Peak to peak intensity of the RPE signal depending on the irradiation dose.

3–Sugar/EPR is sensitivity:

The drawn calibration curves of sugars previously mentioned will allow us to deduce X18MV sugar sensitivity. This sensitivity is represented by the quotient ΔI by ΔD, where ΔI is the variation of a measured signal peak–to–peak intensity, and ΔD is the variation of the dose. The higher the value of its sensitivity the more sensitive the material is. Since the sugar calibration curve is linear, its sensitivity is given directly by the slope of the line. For example, sugar sensitivity is 500u.a/Gy. The obtained results are compatible with other obtained results on various sugars:

- For mannose, Bartlett and Da Costa observed a linearity of the EPR response based on the dose up to 5.10^4Gy and for glucose up to 10^4 Gy [12,13];
- Yordanov Bartlett et.al.observed a linear EPR response/dose up to 10 kGy [14];
- The linearity of the EPR signal/dose was also observed following the irradiation of the sugar by various particles such as gamma rays, neutrons, carbon ions. [4,15–17].

Conclusion

This research aimed at highlighting the dosimetric qualities of a new «sugar/EPR» dosimeter with respect to X18MV beam from a linear accelerator used for radiotherapy treatments which could be used for reliable and accurate dosimetry contributing to the prevention of radiotherapy incidentsand to the protection of cancer patients. Besides being available, inexpensive and easy to prepare, the «sugar/EPR» dosimeter led to other results about other qualities namely:

- A simple and identical form of EPR signal for all irradiated samples with different doses (only the peak to peak intensity varies);
- A low background noise signal;
- A high sensitivity even for low administered doses in radiotherapy;
- A linear calibration curve, making the extrapolation of the absorbed dose easy for each measured intensity.

The obtained results from this study prove that the sugar/EPR system is a good dosimeter, highlighting its interesting dosimetric characteristics, which are compatible with the relevant bibliographic data. Therefore, this dosimeter can be used asa reliable and accuracy dosimetry of X18MV photon beam which contributes to the safety of the patients treated with radiotherapy. In addition to the dosimetry of high energy beams this system could be used for in vivo dosimetry because the dimensions of the dosimeter are small which facilitates its positioning, and therefore it will not affect the treatment dose.

Currently EPR/sugar dosimeter is still in the trial and study phase but to be used for clinical cases it will require consent.

This research was confronted with limits and potential difficulties related to:

- The lack of equipment;
- The service of the radiotherapy where the linear accelerator of particles used for irradiating the samplesis installed and the analysis laboratory were not close;
- The dose measurement is not done in real time, and therefore for cases requiring this kind of dosimetry, the «sugar/EPR» dosimeter cannot be used.

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