Dosimetric characteristics of N-vinylpyrrolidone based polymer gels: utilization depending on dose range

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Abstract. In this study, two types of normoxic N-vinylpyrrolidone based polymer gel, VIPET¹v and VIPET²v, were presented. VIPET²v had the double amount of monomer compared to the VIPET¹v. The influence of this difference in the dosimetric characteristics of the polymer gel dosimeters was investigated. The doubling in N-vinylpyrrolidone concentration increased the dose sensitivity in the linear dose range region and improved the dose resolution at 95% confidence level for lower doses (D<10Gy). Unfortunately, this increase in concentration reduced the dose range response. VIPET¹v was sensitive in the dose range of 2 to 60 Gy, while VIPET²v was sensitive in the dose range of 1 to 30 Gy. Moreover, both gels showed a linear R²-dose response for one month post-irradiation time period. During this time, variations in dose sensitivity and offset values of both dosimeters were observed. Finally, the dose resolution temporal stability was studied and was eventually improved by doubling the N-vinylpyrrolidone concentration.

1. Introduction

Nowadays, several investigators have introduced polymer gel dosimeters with different chemical compositions [1, 2]. Each dosimeter should accomplish specific dosimetric characteristics in order to be used safely in clinical practice of radiotherapy [3, 4]. Recently, there were efforts on the improvement of the dose sensitivity and dose resolution [5, 6] of the polymer gels dosimeters by: (a) the addition of cosolvents or (b) the increase of the total monomer amount of the chemical composition of the dosimeter [7-9].

Pappas et al [10] introduced the anoxic N-vinylpyrrolidone based polymer gel dosimeter (VIPAR) and its dosimetric characteristics. A few years later, a normoxic N-vinylpyrrolidone based polymer gel (VIPET) was presented by Papadakis et al [11]. The aim of this study is to explore the dosimetric characteristics and the usefulness in clinical practice of the two types of normoxic N-vinylpyrrolidone based polymer gels, VIPET¹v and VIPET²v. VIPET²v has the double amount of monomer compared to
the VIPET$^\text{1v}$. In the current study, the influence of the monomer concentration in the normoxic N-vinylpyrrolidone based polymer gels is presented.

2. Materials and methods

2.1. Gel preparation

Two types of normoxic N-vinylpyrrolidone based polymer gels were produced. The first one VIPET$^\text{1v}$ was introduced by Papadakis et al and the second one, VIPET$^\text{2v}$, was based on the similar formula of VIPAR [10] and VIPET [11] polymer gels. In both gels, the gelatin concentration was 5% w/w, the N,N'-methylenebisacrylamide concentration was 4% w/w according to the initial formula of VIPAR and THPC was 5mM according to the VIPET's formula. The only difference between the two types was the monomer concentration. The N-vinylpyrrolidone was 4% w/w for VIPET$^\text{1v}$ (8%T, 50%C) and 8% w/w for VIPET$^\text{2v}$ (12%T, 33%C).

Both manufacture procedures were performed under normal atmospheric conditions inside a laminar flow hood. Firstly, the gelatin was added to the double distilled water and left to dissolve, following by heating to 50°C using a hot magnetic stirrer. Then, the bis was added. After the bis dissolved, the mixture was cooled down to approximately 32°C and the monomer was added. When the solution became transparent, THPC was added. Each solution was filled in two 100mL cylindrical vials. The four vials were stored at 20°C ambient temperature for 24h in a cool and dark place to solidify before irradiation.

2.2. Gel irradiation

The gel phantoms were irradiated in a Primus Clinical Accelerator (Primus, LINAC, Siemens, Germany) using a 6MV photon beam, inside an in-house build solid water structure. Each phantom was irradiated separately in six different areas perpendicular to their length. The field size used to irradiate each area was 2x4 cm$^2$, the source sample distance was 100cm and the dose rate was 3Gy/min. The first vial of each type was irradiated along the central axis of the beam delivering doses at a range of 0.5 to 8 Gy and the second vial of each type was received doses from 10 to 60 Gy. Similar dose measurements were performed separately using a water phantom and an ion chamber and were considered as a dosimetric reference.

2.3. MRI measurements

All polymer gels were repeatedly scanned utilizing a 1.5T whole body MR Imager (Vision/ Sonata, Siemens, Germany) one day, one week, two weeks and one month post-irradiation. A 2D multi-slice-multi echo (32 echoes) spin echo Phase Alternating Phase Shift train sequence (PHAPS) was utilized for the acquisition of the parametric T2 maps. The sequence parameters were: TR=9000 ms, TE=40-1280ms in symmetric TE intervals of 40 ms (echo train), FA=180°, slice thickness=4mm, FOV=250x156 mm$^2$, matrix size=256x256, NEX=1. MR images were transferred and analyzed to a PACS workstation (EvoRad, Athens, Greece) for the specification of dose response, dose resolution of both types of polymer gels.

3. Results

3.1. Dose response and dose resolution

Figure 1 represents the dose response of VIPET$^\text{1v}$ and VIPET$^\text{2v}$ at one day post-irradiation in a dose range of 0.5 to 60 Gy. VIPET$^\text{1v}$ polymer gel exhibits a linear dose response in the dose range of 2-60 Gy. It is observed that VIPET$^\text{1v}$ is not sensitive for doses lower than 2 Gy. On the other hand, VIPET$^\text{2v}$ polymer gel exhibits a linear dose response in the dose range of 1-30 Gy. The VIPET$^\text{2v}$ gel saturates for doses greater than 30 Gy.

In the common linear dose-response region, the dose-R2 data were fitted according to the linear equation: $R2 (D) = \alpha D + R_0$. The calibration procedure for VIPET$^\text{1v}$ yielded a dose sensitivity: $\alpha=$
(0.059 ±0.001) Gy\(^{-1}\)s\(^{-1}\) and an offset: \(R_0 = (1.385 ±0.018)\) s\(^{-1}\), while the calibration procedure for VIPET\(^{2v}\) yielded a dose sensitivity: \(\alpha = (0.063±0.003)\) Gy\(^{-1}\)s\(^{-1}\) and an offset: \(R_0 = (1.148±0.049)\) s\(^{-1}\).

Figure 1: Dose response of VIPET\(^{1v}\) and VIPET\(^{2v}\) at one day post-irradiation.

Figure 2: Dose resolution at 95% confidence level of VIPET\(^{1v}\) and VIPET\(^{2v}\) and the 2\% ICRU limit at one day post-irradiation.

Figure 2 shows the dose resolution at 95% confidence level at one day post-irradiation for both polymer gels including the 2\% ICRU limit (dashed line). VIPET\(^{1v}\) can fulfill the 2\% limit for doses above 2 Gy. While, VIPET\(^{2v}\) can accomplish the 2\% limit for doses below 2 Gy.

3.2. Temporal stability in a time period of one month

Table 1 presents the dose sensitivity and offset values at different time intervals post-irradiation for the time period of one month for both polymer gels. It is obvious that the sensitivity values of VIPET\(^{2v}\) remain larger than the values of VIPET\(^{1v}\) in a month. For both types of polymer gels, the sensitivity reaches a maximum after one week and then ranges in lower values. On the other hand, for both gels the offset value is constantly increased with the post-irradiation time interval.

Table 1: Dose sensitivity and offset values of VIPET\(^{1v}\) and VIPET\(^{2v}\) gels in dose range (0-30 Gy) for a time period of a month.

| Time interval | Dose sensitivity for dose range (0-30Gy) | Offset \((R_0)\) for dose range (0-30Gy) |
|---------------|----------------------------------------|----------------------------------------|
|               | VIPET\(^{1v}\) \((s^{-1}Gy^{-1})\) | VIPET\(^{2v}\) \((s^{-1}Gy^{-1})\) | VIPET\(^{1v}\) \((s^{-1})\) | VIPET\(^{2v}\) \((s^{-1})\) |
| 1 day         | 0.059 ± 0.001                          | 0.063 ± 0.003                          | 1.395 ± 0.024                  | 1.148 ± 0.049                  |
| 1 week        | 0.060 ± 0.001                          | 0.064 ± 0.003                          | 1.477 ± 0.009                  | 1.565 ± 0.047                  |
| 2 weeks       | 0.059 ± 0.001                          | 0.058 ± 0.003                          | 1.566 ± 0.014                  | 1.695 ± 0.046                  |
| 1 month       | 0.060 ± 0.001                          | 0.062 ± 0.003                          | 1.636 ± 0.008                  | 2.103 ± 0.0045                 |

Figures 3 and 4 show the dose resolution at 95% confidence level for VIPET\(^{1v}\) and VIPET\(^{2v}\) polymer gels for a time period of one month. The dose resolution of VIPET\(^{1v}\) for doses below 20 Gy does not change. For the same gel for doses above 20 Gy the dose resolution ranges from 0.07 to 0.4 Gy. Whereas, the dose resolution of VIPET\(^{2v}\) remains constantly stable for a period of one month.

4. Discussion

It has been shown that the doubling of the N-vinylpyrrolidone concentration increased the dose sensitivity in the linear dose range region and improved the dose resolution at 95\% confidence level for lower doses (D<10 Gy). Unfortunately, this increase in concentration resulted in a dose range response restriction. It was also observed that the R2-dose response for VIPET\(^{1v}\) and VIPET\(^{2v}\) polymer gels was maintained linear for a time period of one month post-irradiation. It was suggested that the
changes in dose sensitivity were mainly attributed to the post-irradiation polymerization reactions in the N-vinylpyrrolidone based polymer gels [11-13]. The increase in monomer concentration precipitated the variations in offset values. Finally, the dose resolution temporal stability was improved by the doubling of N-vinylpyrrolidone concentration.

Figure 3: Dose resolution at 95% confidence level of VIPET1v and the 2% ICRU limit for a time period of one month post-irradiation.

Figure 4: Dose resolution at 95% confidence level of VIPET2v and the 2% ICRU limit for a time period of one month post-irradiation.

5. Conclusion
N-vinylpyrrolidone based polymer gels constitute reliable dosimeters in 3D dose verification in radiotherapy. The increase in monomer concentration alters the dosimetric characteristics in terms of dose range, dose sensitivity and dose resolution. As a final statement, it was concluded that the selection of the monomer concentration should be associated with the desired dosimetric characteristics of the polymer gel.

6. References
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