# Polymer gel dosimetry utilizing a 2D (SE) and a 2D (HASTE) multiple echo sequences

**M-V Papoutsaki[1], E Pappas[2], AE Papadakis[3], C Varveris[4], J Damilakis[1] and TG Maris[1]**
[1]Department of Medical Physics, University of Crete, Medical School, Staurakia 71110, Crete, Greece
[2]Department of Medical Radiological Technologists, Technological Educational Institute of Athens, Egaleo, 12210, Athens, Greece
[3]Department of Medical Physics, University Hospital of Heraklion, Staurakia, 711110, Crete, Greece
[4]Department of Radiation Therapy, University of Crete, Medical School, Staurakia, 711110, Crete, Greece

E-mail: vasp3479@yahoo.gr

**Abstract.** Two pulse sequences were used for the estimation of dosimetric characteristics of VIPET polymer gels. The first one, multi- echo spin echo (MESE) is the well-established method for T2 measurements. The other method is a new multi-echo single shot turbo spin echo pulse sequence, MEHASTE that reduces the acquisition time significantly. Both techniques showed a linear R2-dose response. With MESE sequence, the dose sensitivity was slightly enhanced as compared to MEHASTE. The linear portion of the R2-dose curve was restricted using the MEHASTE sequence. For doses above 7 Gy both methods fulfill the 2% ICRU criterion limit for dose resolution estimations (95% confidence level). Finally, for a time period of one month the temporal stability of R2-dose response was maintained stable utilizing both MESE and MEHASTE pulse sequences. MEHASTE serves as an excellent means for fast 3D polymer gel dosimetry.

## 1. Introduction

Precision and accuracy are crucial factors for polymer gel dosimetry applications in clinical practice. The overall polymer gel dosimetry procedure consists of: a) the preparation of a certain chemical composition polymer gel, b) the irradiation, c) the readout process and d) the mathematical analysis method used for the estimation of the final irradiation doses [1]. Nowadays, different imaging modalities applied for the readout and analysis processes are used. These include Magnetic Resonance Imaging (MRI) [2], Optical Computed Tomography (opt-CT) [3], x-ray CT [4] and Ultrasound [5]. Amongst them, MRI is an established methodology as a readout process in polymer gel dosimetry [6]. Several research groups used different pulse sequences for the acquisition of T2 measurements [1]. De Deene et al [7] was the first who introduced the multiple echo (32 echoes) spin echo (MESE) sequence. Utilizing this methodology, the uncertainty of the dose determination related to the pulse sequence was minimized. As a consequence, the last ten years MESE pulse sequence is well-established in MRI polymer gel dosimetry [8, 9]. The main drawback of this pulse sequence is the relatively long acquisition time. The aim of this work is to present a new multi-echo single shot turbo

spin echo sequence (MEHASTE) for MRI polymer gel dosimetry and to compare the results with the standard (MESE) sequence utilizing normoxic N-vinylpyrrolidone based polymer gels [10].

## 2. Materials and methods

### *2.1. Polymer gel manufacture*

300 mL normoxic N-vinylpyrrolidone based polymer gel, VIPET [10] was manufactured, containing 7% w/w gelatin, 4% w/w N-vinylpyrrolidone, 4% w/w N,N'-methylenebisacrylamide (8%T, 50% C) and 5 mM THPC. The polymer gel solution was prepared under normal atmospheric conditions inside a laminar flow hood.

Initially, the gelatin was added to the double distilled water and left to dissolved. Then the solution was heated to $50^0$C using a hot magnetic stirrer. The temperature was stabilized and the bis was added. When the bis had fully dissolved, the solution was cooled down to approximately 32 $^0$C and the N-vinylpyrrolidone was added. Finally, when all the constituents were completely dissolved, the THPC was added. The solution was filled in three 100 mL cylindrical vials and closed using the appropriate caps and Parafilm. The gel phantoms were stored at $20^0$C ambient temperature for 24h in a cool, dark and dry place to solidify before irradiation.

### *2.2. Polymer gel irradiation*

The VIPET dosimeters 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 vial was irradiated at 6 different areas (perpendicular to their length) using different irradiation doses. The delivered doses covered a range from 0.5 Gy up to 60 Gy. The field size of each irradiation was 2x4 $cm^2$, the source sample distance was 100 cm and the dose rate was 3 Gy/min. A water phantom and an ion chamber were utilized for the accomplishment of the similar experiments and these results were considered as a dosimetric reference.

### *2.3. MRI measurements*

All polymer gels were scanned using a 1.5T whole body MR Imager (Vision/ Sonata, Siemens, Germany). T2 measurements were produced employing two different MR pulse sequences at one day, one week, two weeks and one month post-irradiation. Firstly, a 2D non space filling multi-slice- multi echo (32 echoes) spin echo (MESE) sequence was utilized for the calculation of the parametric T2 maps. MESE sequence parameters were: TR=9000 ms, TE=40-1280ms in symmetric TE intervals of 40 ms (echo train), slice thickness=4mm, number of slices= 5, interslice interval (gap) = 4 mm, FOV= 250x156 $mm^2$, matrix size= 256x256, NEX=1, ETL=1, scan time=45 min. Secondly, T2 parametric maps were also calculated utilizing a 2D space filling multi-slice- multi echo (4 echoes) Half-Fourier Acquisition Single-Shot Turbo Spin Echo (MEHASTE) sequence. MEHASTE sequence parameters were: TR=2500 ms, TE=36-1230ms in asymmetric TE intervals (36, 436, 835, 1230 ms), slice thickness=2mm, number of slices= 25, interslice interval (gap) = 0 mm, FOV= 169x270 $mm^2$, matrix size= 256x160, NEX=16, ETL= 160, scan time=15 min. A restore RF pre-pulse was incorporated in the MEHASTE sequence, thus enabling the significant reduction of the TR interval. T2 parametric maps were calculated for both sequences utilizing a weighted linear fitting regression algorithm.

## 3. Results

Dose responses of VIPET gels using both sequences at one day post-irradiation are presented in figure 1. For MESE, VIPET exhibits a linear dose response for doses from 0.5 up to 50 Gy. However, for MEHASTE, VIPET exhibits a linear dose response in a slightly reduced dose region from 10 to 50 Gy.

A linear fit of the form R2 (D) $=\alpha D+R_0$ was applied to R2-dose data at the common linear dose-response region. Dose sensitivity and offset were found to be: i) $\alpha= (0.048 \pm 0.001)$ $Gy^{-1}s^{-1}$ and $R_0=$

(1.614 ±0.050) $s^{-1}$ for MESE and ii) $\alpha$= (0.035 ±0.050) $Gy^{-1}s^{-1}$ and $R_0$= (1.650 ±0.037) $s^{-1}$ for MEHASTE respectively.

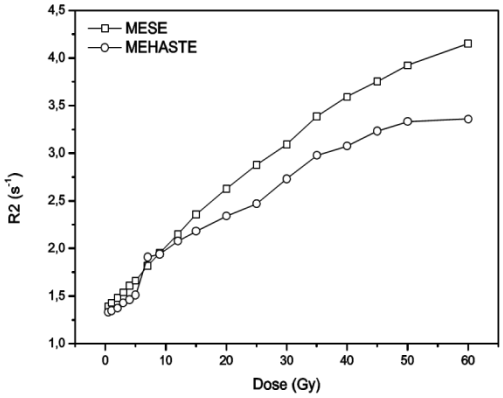


**Figure1:** Dose response of VIPET at one day post-irradiation using MESE and MEHASTE sequences.

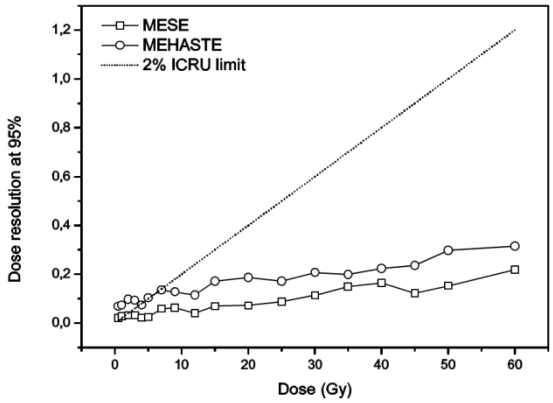


**Figure2:** Dose resolution at 95% confidence level of VIPET at one day post-irradiation using MESE and MEHASTE sequences, including the 2% ICRU limit.

Dose resolution at 95% confidence level at one day post-irradiation utilizing both sequences is presented in figure 2. For MEHASTE, the 2% ICRU limit can be satisfied for doses above 7 Gy, while for MESE above 2 Gy. Dose resolution for MEHASTE sequence ranged from 0.07 to 0.3 Gy and for MESE ranged from 0.02 to 0.2 Gy.

In addition, figures 3 and 4 represent the temporal stability of the R2-dose response at a time period of one month for both sequences. The linear R2-dose response of VIPET gels maintained stable for a time period of one month in both cases. Particularly, the sensitivity was slightly enhanced one week post-irradiation. Moreover, offset values were gradually increased at each time interval.

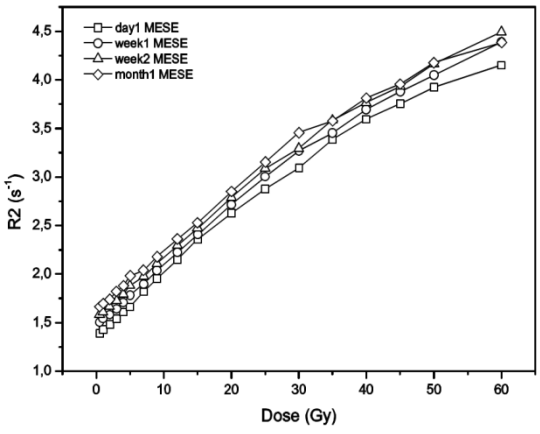


**Figure 3:** Temporal stability dose response of VIPET in one month post-irradiation using the MESE sequence.

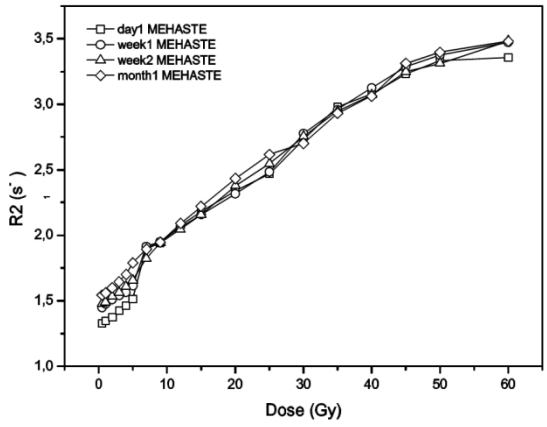


**Figure 4:** Temporal stability dose response of VIPET in one month post-irradiation using the MEHASTE sequence.

## 4. Discussion

Two MRI pulse sequences, MESE and MEHASTE were evaluated as readout processes for the estimation of the dosimetric characteristics of VIPET polymer gels. MESE is the standard sequence for MRI polymer gel dosimetry and MEHASTE is a new multi-echo single shot turbo spin echo sequence. In both sequences, a linear R2-dose response was exhibited. The sensitivity values between MESE and MEHASTE varied less than 30% in the common linear R2-dose region. MEHASTE linear R2-dose region was limited in relation to MESE linear region. For doses above 7Gy, both methods can

fulfill the 2% ICRU limit for dose resolution values at 95% confidence level. The observed slight underestimation of the R2 (overestimation of the T2) values in the MEHASTE as compared to the MESE sequence is mainly due to the extent of the 180 refocusing pulses present in all turbo spin echo sequences. This effect is more prominent in longer R2 (shorter T2) values. The MEHASTE dose resolution values were 50% larger than the MESE related values. In one month period, the linear R2-dose response of the VIPET dosimeter was preserved with both MESE and MEHASTE sequences. Eventually, similar percentage differences between sensitivity and offset values per each time interval were observed using both sequences.

MEHASTE sequences are faster than MESE sequences due to their inherent sequence design (higher ETL factor). The gain in scan time is even higher due to the short TR, which in turn is a direct consequence of the incorporation of the RF restore pre-pulse in the MEHASTE sequence duty cycle. The overall scan time gain is a greater advantage for the final MEHASTE sequence design, enabling the acquisition of 25 thin (2mm) space filling (gap=0) slices in 15 min utilizing 16 excitations. Under these conditions large volume real 3D gel dosimetry is feasible in a reasonable time.

## 5. Conclusion

A new multi-slice multi-echo single shot turbo spin echo sequence (MEHASTE) was presented for the estimation of dosimetric characteristics of polymer gels and was compared with the standard multi-slice multi-echo spin echo (MESE) sequence. It has been shown that the dosimetric results between the two methods did not exhibit large deviations. To conclude, the overall scan time gain in combination with the superb space filling capabilities render MEHASTE sequences as an excellent means for fast 3D polymer gel dosimetry.

## 6. References

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