VIPAR\textsuperscript{nd} - GeVero\textsuperscript{®} tool in planning of TPS scheduled brain tumour radiotherapy

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Abstract. In this paper, VIPAR\textsuperscript{nd} - GeVero\textsuperscript{®} tool is presented for the first time in an application to a brain tumour radiotherapy. Whereas usefulness of VIPAR\textsuperscript{nd} polymer gel in various radiotherapy techniques has recently been confirmed, GeVero\textsuperscript{®} software for calculation of MRI polymer gel data and comparison with TPS dose distribution simulation is now examined. The results demonstrate satisfactory agreement between polymer gel dosimetry-MRI and TPS dose distributions and prove helpfulness of the software and VIPAR\textsuperscript{nd} polymer gel in radiotherapy dosimetry. It is also believed that the software facilitates data processing and therefore should be of further support in po-gel dosimetry studies.

1. Introduction

Polymer gel dosimetry has been established as a powerful method for three-dimensional high resolution measurements of absorbed radiation dose distribution and therefore it has been widely examined in radiotherapy dosimetry applications. As radiation detectors, polymer gels are used that are physical hydrogel matrixes containing radiation sensitive vinyl monomer ingredients. If exposed to ionizing radiation, radical polymerisation and crosslinking takes place leading to formation of large structures scattering visible light. This feature allows for naked eye observation of radiation beams tracks after complex irradiation.

In seventies of the last century the direct relation between polymer molecular weight, crosslinking, polymer chains entanglements and nuclear magnetic resonance relaxation times described professor Charlesby [1,2]. Then, various systems were studied in order to establish relation between radical
polymerisation and crosslinking of aqueous vinyl monomer solutions and NMR relaxation times, e.g. ionizing radiation induced acrylamide polymerisation and formation of hydrogels was analyzed by NMR measurements [3]. It was also possible to derive a method of sol-gel analysis for irradiated aqueous solutions of vinyl substrates and follow polymerisation process in the systems via $T_2$ measurements [4]. The latter studies resulted in several polymer gel compositions based on poly(ethylene glycol) diacylate and $N,N'$-methylenebisacrylamide of acronym PABIG [5,6] as well as N-vinylpyrrolidone and $N,N'$-methylenebisacrylamide. The latter was also analyzed elsewhere and the gel was named VIPAR [7]. Improvement of VIPAR polymer gel composition was a subject of profound studies thereafter and have lead to compositions of much lower dose threshold [8] as well as an addition of normoxic ingredients proposed elsewhere [9] resulted in a composition named VIPARnd of simpler and faster preparation scheme [10,11]. Description of another normoxic $N$-vinylpyrrolidone based polymer gel can be found elsewhere [12].

Currently, magnetic resonance imaging measurement of $T_2$ relaxation time is the most common technique allowing precise and detail analysis of changes inside polymer gels. However, polymer gel MRI data analysis may be lengthy, and requires significant familiarity of DICOM structures, if not accompanied by specific software. Therefore, fast, user friendly software for polymer gels examination was developed in our group. GeVero® software equipped with VIPARnd polymer gel is believed to substantially ease 3D radiation dose recording and data processing. Consequently, in this work we present the first data on application VIPARnd - GeVero® tool in planning of a brain tumor treatment.

2. Materials and methods

2.1. Polymer gel dosimeter

The VIPARnd polymer gel dosimeter ($N$-vinylpyrrolidone 8% w/v, $N,N'$-methylenebisacrylamide 4% (w/v), gelatine 7.5% (w/v), copper sulphate (CuSO$_4\times5$H$_2$O) and L-ascorbic acid of 0.0008% (w/v) and 0.007% (w/v), respectively) was prepared according to the procedure described earlier [10]. Briefly, $N,N'$-methylenebisacrylamide was dissolved in deionised water under stirring and heating below 50°C. Afterwards, gelatine was added and completely dissolved before the solution was cooled down to a temperature of about 33°C in order to add $N$-vinylpyrrolidone. Finally, ascorbic acid and CuSO$_4\times5$H$_2$O were added and the composition was mixed carefully.

Two types of vials for irradiation and magnetic resonance imaging were used. A batch of 0.8 dm$^3$ VIPARnd was prepared to fill in fourteen 50 cm$^3$ long calibration vials. However, 2.5 dm$^3$ of the same polymer gel was prepared for treatment planning verification experiment. In the latter case, a large vial corresponding to the average volume of brain was used.

Notwithstanding the fact that VIPARnd belongs to so called normoxic range of polymer gel dosimeters, all vials were tightly closed to provide stable conditions for polymerization reactions of monomers and prevent the air from inflowing.

2.2. Irradiation

The former scheme of irradiation of the calibration vials was adopted [10]. All vials were irradiated 24 hours post preparation to ensure that the solidification of gelatine is completed. Each 50 cm$^3$ VIPARnd calibration vial was centrally placed inside cubic phantom of RW3 plates (18x18x18 cm$^3$ cube). Prior to irradiation, however, the phantom with VIPARnd vial was scanned (CT, Toshiba, 1 mm step) and 3D images were employed by treatment planning system (TPS, Eclipse External Beam Planning, Anisotropic Analytical Algorithm, AAA, for photons) to calculate three bands of different maximal dose with 5 cm spacing between the centers of consecutive 3.5 cm long bands. The irradiation was performed with the aid of Clinac 600CD, 6MV beam (Varian Medical Systems, Palo Alto, CA; a four-field box technique was applied to irradiate each band). The absorbed dose range was equal 0 – 38 Gy (300 MU min$^{-1}$) (Fig. 1).
Figure 1. RW3 phantom with VIPAR\textsuperscript{nd} calibration vial (left) and the effect of the irradiation of calibration gels (right) (Clinac 600, 300 MU min\(^{-1}\)).

CT images of a patient brain tumor were used for radiotherapy planning with the aid of Eclipse External Beam Planning (Anisotropic Analytical Algorithm, AAA, for photons). This system generated a plan of irradiation of the 2.5 dm\(^3\) VIPAR\textsuperscript{nd} vial. Further, the irradiation plan was put into operation with the aid of Clinac 600 (300 MU min\(^{-1}\), prescribed dose - 36Gy). Results are shown in Figure 2.

![Figure 2](image_url)

Figure 2. The 2.5 dm\(^3\) VIPAR\textsuperscript{nd} vial after irradiation with Clinac 600 (300 MU min\(^{-1}\)) according to brain tumor plan delivered by Eclipse External Beam Planning.

2.3. Magnetic Resonance Imaging

All vials of VIPAR\textsuperscript{nd} underwent MR imaging (Picker Edge 1.5 T) 24 hours post irradiation. Previous protocol was applied [13,14], however in this study, TE where equal 30, 60, 90, 120 ms, echo averaging was set to 1, 2, 4 and 8, 256x256 matrix, 0.78 mm pixel spacing (for the calibration samples). The parameters of MR scanning of the 2.5 dm\(^3\) vial were as follow: TE 30, 60, 90, 120 ms, echo averaging was set to 1, pixel spacing 0.74 mm; slice thickness 1.5 mm; 256x256 matrix. Four echo-based images for each slice of both type vials were obtained. The pixel intensities of the four echo-based images were further analyzed with the aid of GeVero\textsuperscript{®} software.

2.4. Dose distribution calculations

Magnetic resonance DICOM images of irradiated 50 cm\(^3\) and 2.5 dm\(^3\) vials were processed by GeVero\textsuperscript{®} software described elsewhere [15]. The software calculates R2 relaxation rate and absorbed dose distribution in an irradiated gel. Calibration option is one of the features of the software as well as processing of TPS data of a planned dose distribution, here in VIPAR\textsuperscript{nd} polymer gel. Moreover, TPS and VIPAR\textsuperscript{nd} - MRI data were compared: gamma index, isodoses, dose profiles, histograms.

3. Results and discussion

Figure 3 shows calibration R2 dependence on absorbed dose for VIPAR\textsuperscript{nd} gel at different MR setup.
The data revealed no significant difference in dose sensitivity and R2(0) parameters, which were important for further calculations of dose distribution in 2.5 dm³ vial. Therefore, the large gel vial was MR scanned without signal averaging option that significantly reduced the time of measurement. It is also worth mentioning that dose sensitivity value of the gel was found to be similar to the one reported before [10].

In Figure 4, the comparison of TPS calculations and MR measurements for VIPARnd is visualised for selected XY dose plane with the aid of GeVero®. Quantitative and qualitative analysis in all planes (XY, XZ, YZ) and 108 layers revealed good matching of dose distributions in vast majority of the gel layers. Mismatching of dose distributions was also discerned especially close to the glass walls of the gel vial. The discrepancies are to be scrutinised in due time in order to find satisfactory explanation of this phenomenon.

Figure 4. A - GeVero® comparison of dose distribution in VIPARnd 2.5 dm³ vial. The dose distribution data calculated with Eclipse External Beam Planning system and the polymer gel-MRI method (A). B – Gamma index; C – Gamma index histogram; D – isodoses superimposition. The data is presented for selected cross-section of VIPARnd in XY plane.
4. Conclusions
In this work VIPAR\textsuperscript{rd}-GeVero\textsuperscript{®} was presented as prospective tool for user-friendly comparison of calculations against measurements of 3D absorbed dose distributions. The worked out software facilitated typically laborious calculations of polymer gel dosimetry data. A good agreement was found between TPS irradiation plan and the polymer gel-MRI dose distribution.

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References
[1] Charlesby A., The use of pulsed NMR technique in the measurement of radiation effects in polymer, Radiat. Phys. Chem., 14, 919-930 (1979)
[2] Charlesby A., Käfer P., Folland R., Study of very high molecular weight polyethylene using pulsed NMR techniques, Radiat. Phys. Chem., 11, 83-91 (1978)
[3] Rosiak J.M., Burczak K., Pękala W., Piślewski N., Idziak S., Charlesby A. Studies of polymerisation and crosslinking of aqueous acrylamide, Radiat. Phys. Chem., 32, 793-796 (1988)
[4] Kozicki M., Radiation-induced reactions of divinyl monomers and their application in polymer gel dosimetry, PhD thesis at the Institute of Applied Radiation Chemistry, Technical University of Lodz, Poland (2004)
[5] Kozicki M., Rosiak J.M. “Basic properties of a new PABIG polymer gel dosimeter for dose distribution assessment in radiotherapy treatment”, 2\textsuperscript{nd} International Symposium on Reactive Polymers in Inhomogeneous Systems, in Melts and at Interfaces, September 28 – October 1, 2003, Dresden, Germany, book of abstract, S3/33
[6] Pantelis E., Lymeropoulou G., Papagiannis P., Sakellou L., Stiliaris S., Sandilos P., Seimenis I., Kozicki M. and Rosiak J.M., Polymer gel dosimetry close to an 125I interstitial brachytherapy seed, Phys. Med. Biol. 50, 4371-4384 (2005)
[7] Pappas E., Moris T., Angelopoulos A., Paparigopoulou M., Sakellou L., Sandilos P., Voyiatzi S., Vlachos L., A new polymer gel for magnetic resonance imaging (MRI) radiation dosimetry, Phys. Med. Biol., 44, 2677-2684 (1999)
[8] Kozicki M., Petrokoksinos L., Papagiannis P., Sakellou L., Angelopoulos A., Pappas E., Rosiak J.M., Study of VIPAR gel dosimeter dose range improvement, Medical Physics Proceedings of the jointly held Congresses ICMP 2005, BTM 2005, September 14-17, Nuremberg, Germany, Biomedizinische Technik, 50, 1368-1369 (2005)
[9] Fong P.M., Keil D.C., Does M.D., Gore J.C., Polymer gel for magnetic resonance imaging of radiation dose distributions at normal room atmosphere, Phys. Med. Biol., 46, 3105-3113 (2001)
[10] Kozicki M., Maras P., Rybka K., Bieganski T., Kadłubowski S., Petrokoksinos L. On the development of the VIPAR polymer gel dosimeter for three-dimensional dose measurements, Macromol. Symp., 254, 345–352 (2007)
[11] Pantelis E., Antypas C., Petrokoksinos L., Kauriskos P., Papagiannis P., Kozicki M., Georgiou E., Sakellou L. and Seimenis I., Dosimetric characterization of CyberKnife radiosurgical photon beams using polymer gels, Med. Phys., 35, 2312-2320 (2008)
[12] Papadakis A.E., Maris T.G., Zacharopoulou F., Pappas E., Zacharakis G. and Damilakis J., An evaluation of the dosimetric performance characteristics of N-vinylpyrrolidione-based polymer gels, Phys. Med. Biol., 52, 5069–5083 (2007)
[13] Kozicki M., Rybka K., Bieganski T., Petrokoksinos L., Angelopoulos A., 23rd Annual Scientific Meeting of the European Society for Magnetic Resonance in and Biology,
Proceedings September 21–23, Warsaw, Poland p. 107 (2006)

[14] Petrokokkinos L., Kozicki M., Baras P., Angelopoulos A., Papagiannis P., Rybka K., Fijuth J., Bieganski T., Implementing polymer gel dosimetry in clinics with basic MRI installations, Biomedizinische Technik, 50, 1061–1062 (2005)

[15] Kozicki M., Maras P., Jankowski J., Karwowski A.C., Polymer gel - TPS radiotherapy dosimetry GeVero® software for ionizing radiation absorbed dose 3D distribution calculations, submitted to DOSGEL 2008