Polymer gel - TPS radiotherapy dosimetry GeVero® software for ionizing radiation absorbed dose 3D distribution calculations

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Abstract. Implementation of polymer gel dosimetry in radiotherapy departments calls for: easily manufactured gel dosimeters of required physical-chemical properties, set-up procedures of irradiation, adaptation of three-dimensional scanning procedures and instruments as well as fast tool for calculation of 3D absorbed dose distribution in the polymer gel dosimeters and comparison with another treatment planning system calculated dose distribution. These challenges resulted in several propositions in polymer gel dosimetry area. In this work, however, a summary of results on construction of polymer gel dosimetry software facilitating usually laborious 3D dose distributions data processing is provided.

1. Introduction

The polymer gel dosimetry is meant for support of three-dimensional dosimetry in radiotherapy departments. It employs polymer gel dosimeters consisting of gel matrix with monomers inside, which convert to crosslinked structures if exposed to ionizing radiation. If, for example, PABIG [1,2] or VIPAR [3-7] polymer gels are irradiated, water radiolysis radical products are formed: \( \cdot \text{OH}, \cdot \text{H}, \cdot e^- \). The products effectively react with monomer molecules causing monomer radicals formation (initiation step of polymerisation). These radicals are capable of reacting with other monomer molecules leading to formation of a growing polymer chains (propagation step). The propagation step characterises by the increase in molecular weight of polymer and its radius of gyration. The propagation step is very efficient in case of typical monomers of polymer gel dosimeters. This step is followed by termination where dead, non-radical polymer chains are formed. Growing or final chains of polymer can react with monomers, especially difunctional molecules, leading to formation of three-dimensional polymer network (crosslinking reactions).
The products of radical polymerisation and crosslinking can be analyzed with the aid of nuclear magnetic resonance (NMR) relaxation times measurements, since as it was reported earlier [8], their molecular weight influences on NMR relaxation times. Therefore, the technique of magnetic resonance imaging is currently the most commonly used in assessment of radiation-induced changes in polymer gel dosimeters.

The scheme of polymer gel dosimetry application requires irradiation of a gel dosimeter according to a pre-defined irradiation plan. Measurement with the aid of e.g. magnetic resonance imaging and calculation of dose distribution inside polymer gel dosimeter are the following steps. The latter may require significant qualifications if three-dimensional polymer gel data matrix is to be analyzed and compared with a treatment planning system (TPS) calculated dose distribution. In order to simplify this step, we have undertaken to construct software allowing for user friendly readout and processing of polymer gel dosimeter magnetic resonance data as well as comparison with corresponding TPS dose distribution simulation (Fig. 1). Functions of GeVero® software (gel dosimetry verification of treatment planning system software) are illustrated below.

2. Results
GeVero® radiotherapy dosimetry software takes a mathematical approach to calculate 3D radiation dose distribution in polymer gel dosimeters and compares data with 3D radiation dose distribution calculated with the aid of Treatment Planning Systems (TPS). The software was designed to operate in bi-window mode and a user can chose whether to calculate dose distribution in a polymer gel dosimeter or compare and contrast polymer gel-MRI with TPS data.

The main options of the software include:

1. Importing of DICOM data of Magnetic Resonance Imaging (MRI) echo images (or T2 images) of a polymer gel dosimeter; automatic ordering of echo images and assigning them to the appropriate layers of the scanned polymer gel dosimeter.
2. Calculation of spin-spin $T2$ MR relaxation time for each layer of the polymer gel dosimeter.

Input data of signal value and echo time corresponding to echo images of each layer is taken on pixel by pixel basis in order to calculate the function of $y = y_0 + a \cdot \exp(-R2 \cdot t)$, where $y_0$ and $a$ are constants and $R2=1/T2$ – is spin-spin relaxation rate ($T2$ – relaxation time [s]), $y$ – signal value, $t$ – echo time [ms]. Taking logarithm of both sides of the above equation allows for determination of $R2$ and $a$ values.

This procedure leads to $R2$ layers of a polymer gel, which further may be used either for calibration curve parameters or dose distribution calculations.

3. The calibration option for construction a calibration curve: $R2 [s^{-1}] = \text{Dose sensitivity} [\text{Gy}^{-1} \cdot \text{s}^{-1}] \times \text{Dose} [\text{Gy}] + R(0) [s^{-1}]$.

If calibration option is chosen, $R2$ matrixes for calibration samples must be calculated first. Then, it is possible to create a new calibration table that includes information on absorbed dose by polymer gel samples and corresponding $R2$ values. Additionally, the table stores all necessary characteristics of a gel dosimeter, such as irradiation and scanning date, irradiation source features and irradiation conditions, composition of a polymer gel, MR scanning protocol, etc.

GeVero\textsuperscript{®} calculates the dose sensitivity parameter and $R2(0)$ – relaxation rate at $0\text{Gy}$, on the basis of the least squares method. The calibration curve equation is attached to the calibration table together with dose resolution information for a polymer gel dosimeter (Fig. 2).

Figure 2. GeVero\textsuperscript{®} when calculates $R2$ and dose distribution in long 50 cm\textsuperscript{3} vials of VIPAR\textsuperscript{nd} as well as a trial calculation of VIPAR\textsuperscript{nd} calibration curve.

If dose distribution needs to be calculated, the dose option should be used. A user is asked to type conversion parameters for a particular polymer gel, which are $R2(0)$ [1/s] and a $[1/(\text{Gy} \cdot \text{s})]$ – dose...
sensitivity. Those parameters should be searched in appropriate calibration table files. Afterwards, dose distribution is calculated. Further, vectorial transformation and isodose centre selection is performed for the dose distribution 2D matrix in order to create 3D dose matrix, if comparison with TPS dose distribution simulation is considered.

4. Importing TPS dose distribution data, dose distribution visualization in 3D, comparing and contrasting polymer gel dosimetry vs. TPS data (gamma parameter, histograms, isodoses, 2D dose difference).

This part of the software permits an import and separate analysis of polymer gel dose distribution data or treatment planning system dose distribution (import of DICOM RT, e.g. Eclipse system). Comparative analysis of data coming both form calculation methods is also feasible. In each case of separate data analysis, absolute and relative dose profiles as well as histograms drawing can be performed. When both data of dose distributions are imported, one can compare and contrast them thanks to the option of superimposition the data on each other and calculation of isodoses (qualitative comparison) as well as dose profiles or gamma index on the basis of Low et al approach [9] (quantitative comparison). Subtraction of 2D dose distributions of two different data is also possible.

Figure 3. GeVero® when compares two data of various planning systems via gamma index (upper right), isodoses (middle right) and absolute dose profiles (lower right) superimpositions. The six graphs counting form left correspond to two data set on the planes of XY, ZX, YZ. Visualization of separate single data for detailed inspection is feasible.

3. Conclusion
GeVero® radiotherapy dosimetry software eases and shortens time of calculations of dose distributions in polymer gel dosimeters. In combination with PABIG™ and VIPAR™ compositions [5,6] of simplified preparation procedures it is believed to have been complementary solution towards
facilitation of routine application of the gel dosimetry technique. Currently, further studies on function of GeVero®-VIPAR®/PABIG® in radiotherapy dosimetry are ongoing.

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