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Application of optical methods for dose evaluation in normoxic polyacrylamide gels irradiated at two different geometries

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ABSTRACT

Normoxic gels are frequently used in clinical praxis for dose assessment or 3-D dose imaging in radiotherapy due to their relative simple manufacturing process under normal atmospheric conditions, spatial stability and well expressed modification feature of physical properties which is related to radiation induced polymerization of gels. In this work we have investigated radiation induced modification of the optical properties of home prepared normoxic polyacrylamide gels (nPAG) in relation to polymerization processes that occur in irradiated gels. Two irradiation geometries were used for irradiation of gel samples: broad beam irradiation geometry of teletherapy unit ROKUS-M with a 60Co source and point source irradiation geometry using 192Ir source of high dose rate afterloading brachytherapy unit MicroSelectron v2 which was inserted into gel via 6 Fr (2 mm thick) catheter. Verification of optical methods: UV–VIS spectrometry, spectrophotometry, Raman spectroscopy for dose assessment in irradiated gels has been performed. Aspects of their application for dose evaluation in gels irradiated using different geometries are discussed. Simple pixel-dose based photometry method also has been proposed and evaluated as a potential method for dose evaluation in catheter based interstitial high dose rate brachytherapy.

1. Introduction

Polymer gel dosimetry is based on the radiation-induced polymerization and cross-linking of aqueous monomers infused in a gelatin matrix. When irradiated, free radicals created in the gel induce polymerizations restricted to the irradiated region. The properties of polymerized gels depend on chemical components and their concentrations as well as on gel production technology and irradiation conditions. Being tissue equivalent gel acts as a phantom as well as dosimeter and there is no need for dose perturbation correction. Gel dosimetry is well established in external radiotherapy. Many investigations related to development and evaluation of gels for dose assessment and verification have been performed and results reported over the years as it might be recalled from the reference list of [1,2] and [3]. Application of gel dosimeters is of advantage when irradiation techniques are associated with patient movement, small irradiation fields and steep dose gradients as it is in the case of brachytherapy.

In vivo dosimetry has been used in brachytherapy for decades and has been referred to in International Commission on Radiation Units and Measurements (ICRU) recommendations [4]. Different methods and detectors have been applied for dose evaluation for organs at risk and 3-D dose verification in brachytherapy. Nevertheless the accurate evaluation of the doses to patients especially in interstitial high dose rate brachytherapy remains within the scope of future developments [5]. Catheter based dosimetry, which is applicable in interstitial brachytherapy, is one of possible methods to measure absorbed dose direct in the tumor tissue. Applying this method, detectors for dose measurements are inserted into flexible catheters that are implanted into tumor prior to start a treatment of patient. Evaluation of detectors most frequently used for this purpose (thermo luminescence detectors (TLD), diodes, metal–oxide–semiconductor field-effect transistors (MOSFET), Alanine detectors, radio luminescence (RL) detectors and position sensitive detectors (PSD)) is given in a recent paper of Tanderup et al. [5]. Tissue equivalent gel dosimeters are not discussed in this paper, but might be also added to this list. Application of polymer gel dosimetry for catheter based in vivo brachytherapy is not verified yet, but there are some promising results on application of Fricke gels [6,7]. Reliability of dose evaluation method and proper dose calibration within a small volume of polymeric gel is one of the main challenges. Started by Maryanski et al. [8] and followed by many authors magnetic resonance imaging (MRI) was found being most suitable for dose evaluation in irradiated polymer gels, but also X-ray CT [9–11], ultrasound [9,12], vibrational spectroscopy [13,9], optical CT [14] and other optical methods [15] are used recently.

The aim of this work was to asses radiation induced polymerization processes and their influence on modification of optical

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properties in irradiated normoxic polyacrylamide gels (nPAG), to verify application of different optical methods for dose assessment in gels irradiated using broad beam and point source geometry, to perform dose calibration and to discuss possibility of polymer gel application as a catheter filling for dosimetry in catheter based interstitial brachytherapy.

2. Instruments and methods

2.1. Gel fabrication

Normoxic PAG gel consisting of 3% w/w Acrylamide, AAm (electrophoresis grade ≥ 99%, powder, Sigma Aldrich), 3% w/w *N*, *N*′-methylene-bis-acrylamide, BIS (electrophoresis grade ≥ 98%, powder, Sigma Aldrich), 5% gelatin (swine skin, 300 bloom, Sigma Aldrich) and 80% w/w of ultrapure deionized water (resistivity > 18.2 MΩ/cm) has been prepared at normal atmospheric conditions as it was described in [16]. The only difference from the described method was that after mixing with water at room temperature, gelatin was left to swell for 30 min and then the whole mixture was heated to 45 °C until the gelatin was completely dissolved. The monomers were added before cooling the mixture to 35 °C. The gel was stirred continuously throughout the entire mixing procedure. After 10 min before the gel was poured into the vials, 10 mM of oxygen scavenger (hydroxymethyl) phosphonium chloride (techn. ~80% in water, Sigma Aldrich), short name—tetrakis (THP), was added. Prepared gel was poured into different vials. 8 glass flasks (D=2.75 cm, H=5.6 cm) filled up to 4 cm high columns with gel were prepared for experimental investigations of gel polymerization caused by ^{60}Co source irradiation (broad beam geometry). A number of fully filled standard cuvettes ($1 \times 1 \times 5$ cm^3) were used for dose calibration purposes. 5 borosilicate beakers (DIN 12 331. ISO 3819; D=4.8 cm, H=8.0 cm) were filled with gel up to 5 cm high columns and supplied with one centrally arranged 6 Fr (D=2 mm) catheter which was used for the insertion of ^{192}Ir brachytherapy source. These beakers were used for experimental investigation of gel polymerization caused by point source irradiation. All vials were closed tightly and left to set in the dark at room temperature for about 24 h before irradiation.

2.2. Gel irradiation

Irradiation of different gel samples was performed in medical teletherapy unit ROKUS-M with ^{60}Co source (broad beam geometry) and high dose rate after loading brachytherapy unit MicroSelectron v2 with ^{192}Ir source (point source geometry) on the same day. ^{60}Co source activity was 4.28×10^{13} Bq and the dose rate measured at 100 cm distance from the source was 0.25 Gy/min on the day of irradiation. ^{192}Ir source had the activity 0.35×10^{12} Bq and the dose rate measured at 1 cm distance was 0.73 Gy/min on the same day.

Broad beam geometry was realized using 10×10 cm^2 irradiation field and 100 cm distance from ^{60}Co source. Arrangements were undertaken to deliver 100% of the dose at 0.5 cm depth beneath of photon entrance surface in central position of the irradiation field of the teletherapy unit. Absorbed dose was registered by the teletherapy unit itself and additionally checked with ionisation chamber (PTW30013-3225) which was fixed at 0.5 cm level beneath of the entrance surface as close as possible to central position of the irradiation field. This experimental set up was described in our previous work [17].

Each gel sample (cuvette or flask) was placed bottom up in a central position of the irradiation field and irradiated to a certain dose. Absorbed doses were 0.5 Gy, 1.0 Gy, 1.5 Gy, 2.0 Gy, 2.5 Gy, 3.0 Gy, 3.5 Gy and 4.0 Gy, respectively. The distance to the source was adjusted for each sample separately. Irradiation of samples and dose measurement were performed in air. Conversion factors were used to convert dose in air to dose in water where appropriate [18].

Since in our previous experiments we have not succeeded to obtain dose depth distribution in one gel filled vial, additional holder was mounted to the ionization chamber keeping the same distance from the photon entrance surface. Holder was positioned centrally in the irradiation field for the insertion of the cuvette. This equipment was used for the dose measurements at certain distances from the photon entrance surface when 100% dose was delivered at 0.5 cm depth. Doses measured using ionization chamber and doses derived from irradiated gels evaluation were used for the construction of the dose–depth curves in the case of broad beam geometry irradiation in teletherapy unit.

Point source irradiation was performed inserting ^{192}Ir source into catheters that were centrally arranged in borosilicate beakers filled with gel as it was described in 2.1 section of this paper. Absorbed doses in different beakers were 1 Gy, 2 Gy, 3 Gy, 4 Gy and 5 Gy, respectively.

The irradiation geometry was set in a way which is applicable in catheter based interstitial brachytherapy treatment when catheters are plane parallel implanted into tumour following Paris system [19,20]. 100% dose was set at the radial distance of 1.1 cm from the longitudinal source axis, taking into account a real size of encapsulated brachytherapy source (D=1.4 mm) and diameter of 6 Fr catheter (D=2 mm) which was installed into gel for the insertion of radiation source. Measurement point of 100% dose at the radial distance of 1.1 cm was chosen to cover the range between two catheters which is 1.5 cm in such arrangement.

2.3. Gel evaluation

Polymerization processes in irradiated gels were analysed using Raman scattering spectrometer Yvon Jobin with Nd:YAG laser (λ=532.3 nm, P=50 mW, beam spot size 0.32 mm). Raman spectra were measured within wavenumber range of 1200–3200 cm^{-1} and bonding structure in gels was assessed. The overlapped background-corrected Raman spectral bands were fitted with Gaussian contours, using least square fitting software. UV–VIS spectrometer Optic Ocean USB 4000 (wave length rage 200–800 nm) and Jasco V650 spectrophotometer (wave length range 300–800 nm) were used to investigate radiation induced spectral changes and modification of optical characteristics of the irradiated gels. Laser light transmission experiment (Ne laser, λ=634 nm) was performed with the aim to evaluate polymerization propagation range of the irradiated gels using experimental set up provided in Fig. 1. Moving the table with sample the

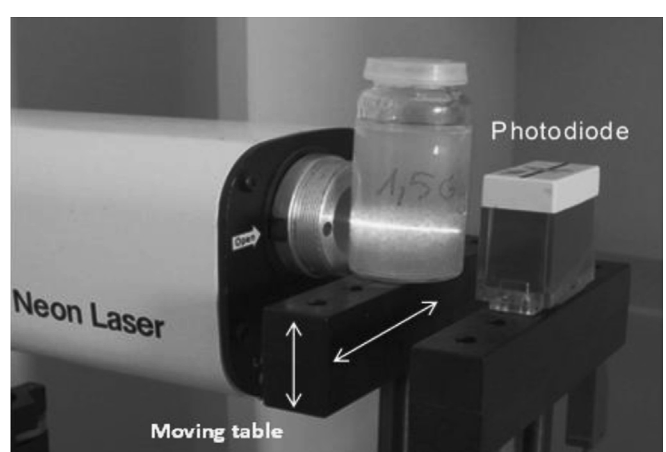

Fig. 1. Experimental set up for polymerization range estimation in irradiated gels using laser beam scanning.