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The comparison of the proton dose distribution calculated with the treatment planning system and measured with alanine detectors in the eye phantom irradiated under therapeutic conditions

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HIGHLIGHTS

- We confirmed the utility of alanine for in-phantom measurements in proton beams.
- We compared TPS-planned and measured doses in proton eye radiotherapy simulation.
- We discovered the limitation of alanine in registration the high dose gradients.

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ABSTRACT

The paper describes the applicability of commercially available alanine detectors produced by Synergy Health for verification of the dose distribution calculated by the treatment planning system (TPS) used in proton eye radiotherapy – Eclipse Ocular Proton Planning (EOPP) program, version 8.9.06, Varian Medical Systems. The TPS-planned dose distribution at selected points in the eye phantom is compared to the dose registered by alanine detectors at these points during a simulated therapeutic irradiation at the proton eye radiotherapy facility in the Henryk Niewodniczanski Institute of Nuclear Physics (IFJ PAN), Krakow, Poland. The phantom was irradiated to obtain, a typical for choroidal melanoma, fraction dose of 15 CGE (13,64 Gy) at the tumor location. The dose registered with alanine pellets located inside the simulated tumor volume demonstrates a good agreement with the TPS-planned dose. The typical for proton radiotherapy, steep dose fall-off outside the treated area is registered by the alanine pellets however, it is difficult to assess it quantitatively, because the dose related EPR signal is registered from the entire pellet volume.

1. Introduction

Electron paramagnetic resonance spectrometry (EPR) of the amino acid L-α alanine CH_3–$CH(NH_2)$–COOH has been known as a dosimetry method for many years (Bradshaw et al., 1962; Regulla and Deffner, 1982). EPR/alanine dosimetry, which is commonly used as a reference technique in conventional radiotherapy (Helt-Hansen et al., 2009), has recently gained attention as a potential tool for dosimetry in proton and ion radiotherapy as well (Onori et al., 2006). Alanine as a passive, integrating detector is mainly used for quality assurance (QA) and quality control (QC) procedures, e.g., beam control, dose delivery control or dose distribution control including control of the dose distribution calculated by treatment planning systems (TPSs).

At the Henryk Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences in Krakow (IFJ PAN), EPR/alanine dosimetry is being introduced as a part of the QA and QC system for proton eye radiotherapy. In this paper, we describe the applicability of alanine for the verification of the TPS-planned dose distribution at selected points in the eye phantom against the dose measured (with alanine detectors) at these points.

2. Materials and methods

2.1. Alanine detectors

In this study, commercially available pellet-shaped detectors (4.8 mm in diameter, 3.0 mm height), manufactured by Synergy

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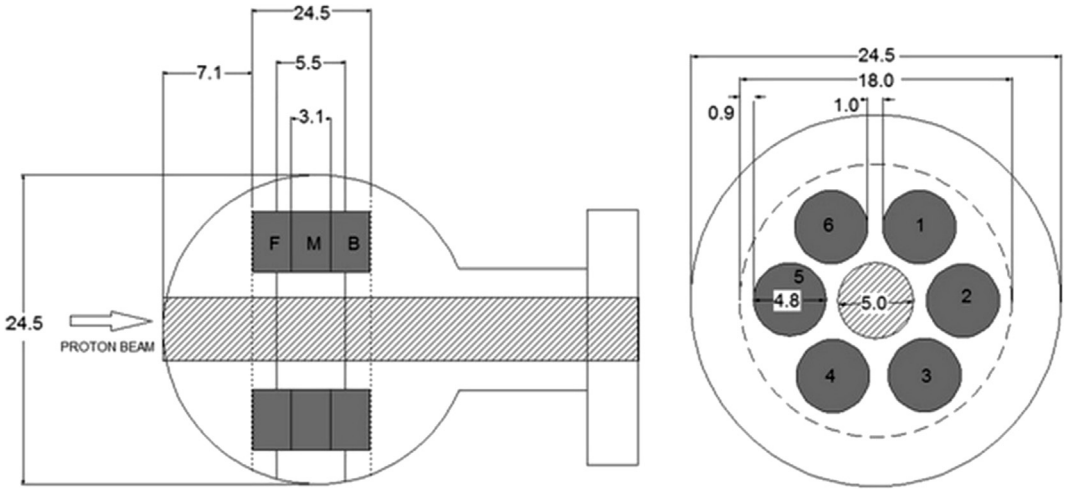

Fig. 1. The dedicated PMMA eye phantom for alanine irradiations. The positions of alanine detectors in layers (F – front layer, M – middle layer, B – bottom layer) and in wells (1–6) as well as proton beam direction are marked.

Health (former name Gamma Service), consisting of 96% alanine and 4% binder by weight, were used.

For the calibration, pellets were irradiated at the IFJ PAN in a modulated 60 MeV proton beam. The reference dosimetry for proton irradiations was performed with a 0.055 cm^3 Markus type parallel plate chamber, calibrated in Co-60 field following the TRS-398 code of practice (TRS, 2000) in terms of dose to water. According to TRS-398, to obtain the dose values in the proton beam, the correction factor for the differences in a chamber response in ^{60}Co and proton field were considered.

2.2. Preliminary experiments

To validate the applicability of the alanine detectors for proton dosimetry in an eye phantom, a preliminary experiment was performed. The dedicated PMMA eye phantom with a diameter of 24.5 mm (which corresponds to a typical eye globe diameter) was designed and manufactured. It consists of three layers. There are 6 peripherally spaced wells, numbered from 1 to 6 (Fig. 1), in the middle layer of the phantom. It is possible to place a stack containing 3 alanine pellets, one on top of the other, in each well. The pellet location inside a well can be identified as a front (F), middle (M) and bottom (B) position (Fig. 1). Up to 18 alanine detectors can be irradiated simultaneously in the phantom.

In the experiment, alanine pellets have been irradiated in the phantom in a spread-out Bragg peak (SOBP) with the range of 28.6 mm and a modulation of 20.1 mm. The dose in the SOBP plateau region equaled 13.64 Gy, which corresponds to a typical fraction dose in proton choroidal melanoma radiotherapy of 15 CGE[1] (Cobalt Gray Equivalent). The final proton beam was then shaped with a circular or a semicircular collimator (both with the diameter of 25.0 mm). Under these irradiation conditions, the pellets situated in the front layer (the beam view) were not fully placed in the SOBP plateau.

The doses measured with alanine pellets in the eye phantom in this experiment were then compared with the model calculation. MCNPX (Pelowitz, 2008) was used to simulate the experiment.

[1] CGE (Cobalt Gray Equivalent) – the term describing the dose in proton radiotherapy, which states the equivalent biological dose and includes the RBE (Relative Biological Effectiveness) factor of 1,1 for protons. It means that for every 1 Gy, the biological effectiveness of a proton beam is similar to what is seen with 1.1 Gy of standard X-rays (Skinner and Komaki, 2012).

2.3. Monte Carlo simulation of the preliminary experiments

The Monte Carlo (MC) proton source was positioned just before the collimators and represented a hardly idealized beam at this point of the experimental set-up. Instead of a slight divergence of the beam resulting from the scattering of the beam protons on all materials on their path from the cyclotron to this point, the initial directions of the MC source protons were parallel to the direction of the beam. They started homogenously from a disc measuring 25 mm in diameter and producing a flat and uniform space distribution. The MC proton source energy distribution was designed to create the same SOBP in a water phantom as the one produced by the energy modulator used in the real experiment.

In the MC simulation of the experiment involving proton irradiation of the eye phantom through the differently shaped collimators, instead of the absorption in the collimator material, histories of protons that there were beyond the aperture of the collimator were eliminated. Finally, protons that reached the eye phantom interacted with the matter of the phantom and the alanine pellets in which the proton energy deposition was scored and expressed in MeV/g/(proton of the source).

The doses recorded by alanine pellets in the experiment show a good correlation with data from the MC simulations. The simulated and measured doses are equal within the measurement uncertainties; however, a systematic error occurred because MC doses were lower than measured (Figs. 2 and 3). The experimental results confirmed the usefulness of the alanine pellets for in-phantom dose distribution measurements. Consequently, the in-phantom irradiations of alanine detectors under therapeutic conditions specified by TPS were performed.

2.4. The TPS-planned dose distribution in the eye phantom vs. the dose distribution measured with alanine detectors

The virtual tumor (Fig. 4) was simulated inside the spherical eye model (the sphere diameter – 24.5 mm) in the treatment planning program dedicated to proton eye radiotherapy – Eclipse Ocular Proton Planning (EOPP), version 8.9.06, Varian Medical Systems (Varian Medical Systems, 2009). The tumor parameters were as follows: location – left eye, nasal, bottom; maximal tumor base – 17.95 mm; minimal tumor base – 9.32 mm, apex height – 7.3 mm, distance to disc edge – 3.91 mm, distance to macula edge – 4.8 mm.