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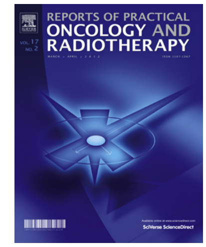

Original research article

Wax boluses and accuracy of EBT and RTQA radiochromic film detectors in radiotherapy with the JINR Phasotron proton beam

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A R T I C L E   I N F O

Article history:
Received 21 November 2012
Received in revised form 3 May 2013
Accepted 16 May 2013

Keywords:
Dosimetry
Proton therapy
Radiochromic films

A B S T R A C T

Aim: To present the results obtained using radiochromic films EBT and RTQA 1010P for the reconstruction the dose distributions for targets irradiated by proton beam and modified by wax boluses.

Background: In Medico-Technical Complex at the Joint Institute for Nuclear Research in Dubna implemented technology of wax boluses.

Materials and methods: Wax boluses are easier to make and they give better dose distributions than boluses made from modeling clay previously used at our center. We irradiated two imaginary targets, one shaped as a cylinder and the other one as two cuboids. The evaluated calibration curve was used for calculation of the dose distributions measured by the EBT and RTQA radiochromic film. In both cases, the measured dose distributions were compared to the dose distributions calculated by the treatment planning system (TPS). We also compared dose distributions using three different conformity indices at a 95% isodose.

Results: Better target coverage and better compliance of measurements (semiconductor detectors and radiochromic films) with calculated doses was obtained for cylindrical target than for cuboidal target. The 95% isodose covered well the tumor for both target shapes, while for cuboidal target larger volume around the target received therapeutic dose, due to the complicated target shape. The use wax boluses provided to be effective tool in modifying proton beam to achieve appropriate shape of isodose distribution.

Conclusion: EBT film yielded the best visual matching. Both EBT and RTQA films confirmed good conformity between calculated and measured doses, thus confirming that wax boluses used to modify the proton beam resulted in good dose distributions.

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http://dx.doi.org/10.1016/j.rpor.2013.05.007

1. Background

Proton beam radiotherapy (PBRT) has gathered much attention in recent years due to its theoretical advantages over conventional external beam radiotherapy (EBRT). In contrast to EBRT, in which much of the energy is absorbed by healthy tissue as the beam passes through on its way to the target, in PBRT most of the energy is delivered to the target. This pattern of energy deposition, known as the Bragg peak, makes proton therapy especially advantageous in the treatment of tumors surrounded by critical structures.[1,2] For this reason, PBRT is being used in pediatric patients to prevent radiation-induced secondary tumors[3,4] and increasingly in some head and neck tumors as well as for prostate cancer. The major drawback of PBRT is significantly higher price of technology required and also more complicated dosimetry and quality procedures.[2,5,6] In the meantime photon and electron radiotherapy has developed enormously and can offer sophisticated tools which allow on very accurate dose delivery to the target with substantial reduction of dose to critical organs.[7–13]

An important issue in PBRT is in achieving dose conformity in the distal part of the tumor. This difficulty can be overcome by the use of a bolus, which is used to account for heterogenous tissue in the path of the beam and to adapt the proton range to the shape of the tumor. The ideal bolus should be made of safe, tissue-equivalent material that is durable, cost-effective, and sufficiently flexible to conform to the patient's body. Up until quite recently, at our center boluses were made of modeling clay. However, the high plasticity and low melting point were sometimes problematic. In addition, the bolus was formed partially by hand and thus lacked precision. To overcome these shortcomings, we recently switched to a different material – special wax for machine processing. Wax boluses have numerous theoretical advantages: they are milled by a computerized machine that produces a precisely-made bolus in accordance with the treatment plan coordinates (x, y, z). In addition, wax boluses have a higher melting point than modeling clay boluses (116 °C vs. 65 °C), and they are more resistant to mechanical injury.

Accurate dose determination and precise dose delivery are essential in all types of radiotherapy,[7] but particularly in PBRT due to the patterns of energy deposition. For this reason, numerous dose verification and calibration methods have been created. ICRU 59 describes the use of ionization chambers for proton dosimetry,[8] although other methods, such as semiconducting detectors, can be used for this purpose. However, in recent years, improvements in radiochromic film (RCF) dosimetry have made this technique a powerful tool for treatment verification and quality assurance. RCFs are used in conventional radiotherapy with photons, but they are also good detectors for the dosimetry of the proton beam because they can be positioned along the beam axis in a water phantom.[9,14] Several authors have described different types of radiochromic films to measure proton dosimetry, including Vatnitsky et al.[15] and Ciangaru et al.[16] The advantages of RFCs are that they are sensitive to ionizing radiation, and change color in response to the delivered radiation, with darker colors indicative of higher doses. Moreover, RCFs are easy to handle and prepare because they are not sensitive to room lights, they develop automatically (unlike radiographic films), and facilitate reading of the absorbed dose. Several different types of RCF have been developed, with two of the most common being EBT and RTQA radiochromic films.[17]

2. Aim

The present study had two primary aims: (1) to evaluate the ability of wax boluses to produce a specific dose distribution; and (2) to compare two types of radiochromic films used to verify the accuracy of the calculation algorithm for the proton beam at our center (Medico-Technical Complex of the Joint Institute for Nuclear Research at Dubna, Russia).

3. Materials and methods

3.1. *Treatment planning system, targets, conditions of irradiation*

We used the TPN 3D treatment planning system (TPS), developed at the Loma-Linda University Medical Center, California, USA. This TPS was adapted for proton beams delivered by the JINR Phasotron with output energy of 660 MeV. For medical applications the energy of protons is reduced to 175 MeV and such beam was used in the study.

For this study, we created two distinct shapes for the irradiated targets and a separate treatment plan for each of them. Both shapes were basic geometric figures with a volume of about 125 cm^3, and they are shown in Fig. 1.

Measurements were made in an almost tissue-equivalent environment (water). The geometric targets were virtually immersed in a PMMA tank with internal volume of 254 mm × 160 mm × 201 mm produced at the MTC workshop. The tank was filled with water for the irradiation process. We used a 60 mm × 60 mm collimator with a ridge filter to spread-out the proton beam Bragg peak to the size of targets.

3.2. *Wax boluses*

Boluses are produced individually for each patient and for each irradiation angle. Boluses were mechanically milled to match the coordinates calculated by the TPS. The boluses used in the study are presented in Fig. 2.

3.3. *Dosimeters*

We used two types of RC films: EBT and RTQA 1010P (International Specialty Products, Wayne, NJ, USA) to measure dose distributions. These films can be used in a water environment because the film layers are not affected by water. EBT film consists of two active layers (i.e., responsive to radiation) and two outer layers of transparent polyester. RTQA film has one active layer and one layer of transparent polyester, colored in yellow and one layer of white nontransparent polyester.

3.4. *Calibration of detectors*

Films were cut into 8 small pieces 20 mm × 20 mm in dimension and were irradiated with the following doses: EBT films