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ORIGINAL PAPER

Dosimetric verification of a high dose rate brachytherapy treatment planning system in homogeneous and heterogeneous media

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Abstract *Objectives:* To verify the dosimetric accuracy of treatment plans in high dose rate (HDR) brachytherapy by using Gafchromic EBT2 film and to demonstrate the adequacy of dose calculations of a commercial treatment planning system (TPS) in a heterogeneous medium.
Methods: Absorbed doses at chosen points in anatomically different tissue equivalent phantoms were measured using Gafchromic EBT2 film. In one case, tandem ovoid brachytherapy was performed in a homogeneous cervix phantom, whereas in the other, organ heterogeneities were introduced in a phantom to replicate the upper thorax for esophageal brachytherapy treatment. A commercially available TPS was used to perform treatment planning in each case and the EBT2 films were irradiated with the HDR Ir-192 brachytherapy source.
Results: Film measurements in the cervix phantom were found to agree with the TPS calculated values within 3% in the clinically relevant volume. In the thorax phantom, the presence of surrounding heterogeneities was not seen to affect the dose distribution in the volume being treated, whereas, a little dose perturbation was observed at the lung surface. Doses to the spinal cord and to the sternum bone were overestimated and underestimated by 14.6% and 16.5% respectively by the TPS relative to the film measurements. At the trachea wall facing the esophagus, a dose reduction of 10% was noticed in the measurements.
Conclusions: The dose calculation accuracy of the TPS was confirmed in homogeneous medium, whereas, it was proved inadequate to produce correct dosimetric results in conditions of tissue heterogeneity.

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Introduction

Brachytherapy is aimed to treat malignancies by placing radionuclides near the tumor volume in order to maximize the dose delivered to the tumor and minimize the dose delivered to the surrounding healthy tissues. High dose rate (HDR) brachytherapy offers the advantage of highly conformal and precise dose delivery to the malignant tissues as it can directly irradiate the tumor and minimize damage to normal surrounding tissues [1]. Prior to the patient treatment, precise dose calculation is of vital importance because the administered dose per fraction is very high and inaccuracies in dose distribution may lead to critical damage to normal tissues and inappropriate target dosage. The modern HDR brachytherapy treatment planning systems (TPS) rely heavily on dose optimization software which can tailor doses to specific clinical needs without knowing the composition of the tissue through which radiation transport is taking place in actual treatment conditions. In the process of optimization, the dwell times for a number of dwell positions are computed to deliver a prescribed dose to the target or dose constraint points and the corresponding three dimensional dose distributions are presented. With the advancement in imaging and communication technology, the dependency on TPS calculated dose distribution has increased. Due to the complex and variable nature of the treatment planning process, the dosimetric verification of HDR treatment planning system (TPS) is necessary rather than simply relying on the computed results. The verification of the TPS calculated doses by experimental and Monte Carlo simulation methods have been reported in the literature [2—5]. Also, the current TPS dosimetry algorithms are based on the superposition of single source dose distributions in homogeneous water medium, so they do not fully exploit the information available from patient images. Many investigators [6—12] have recognized that significant dose calculation errors are introduced due to the effect of inherent patient heterogeneities. This work presents the dosimetric verifications of treatment plans in HDR brachytherapy by using Gafchromic EBT2 films and also demonstrates the TPS inability to accurately account for material heterogeneities. For this purpose, two anatomically different cases were considered, in which the first case of tandem ovoid brachytherapy of carcinoma cervix assumed a homogeneous tissue equivalent medium for dose measurement while the second case of esophageal brachytherapy included the presence of heterogeneous structures around the source.

Materials and methods

HDR treatment unit and the TPS

A microSelectron HDR v2 remote afterloading brachytherapy unit (Nucletron International B. V., The Netherlands) along with a computed tomography (CT) based brachytherapy TPS, Oncentra MasterPlan version 3.3 was used for HDR treatments. The TPS uses the AAPM Task Group-43 (TG-43) formalism [13,14] for dose calculation and includes various methods of optimization of the treatment dose distribution such as geometrical optimization, graphical optimization, manual adjustment of dwell weights/times and IPSA (inverse planning by simulated annealing) [15]. The source strength was verified using a well type ionization chamber (HDR 1000 Plus, Standard Imaging, US) which was calibrated at the University of Wisconsin Accredited Dosimetry Calibration Laboratory. The local measured and the vendor quoted source strengths were found in excellent agreement within 1%.

Radiochromic film dosimetry system

The Gafchromic EBT2 film (ISP Technologies, Lot Number F020609) used in this study is an improved uniformity, high resolution and high sensitivity radiochromic film which can be used in the dose range of 0.01—40 Gy. Further details about the composition and dimensional aspects of the film are available elsewhere [16]. The EBT2 film is a favorable 2D dosimeter due to its radiological tissue equivalency, real time development, ease of use, and low cost. The film is a practical dosimeter for phantom studies because it can be cut in any shape and size for placing in a specially designed or custom made dosimetry phantom. The read-out of the films irradiated during the calibration and experiment was carried out using a flatbed scanner (Epson Expression 10000 XL) and the film images were analyzed using Image J software. The exposed film samples were scanned 48 h after irradiation following a constant scan set-up to ensure optimum growth of optical density and consistency in the evaluation purpose [17,18].

As the EBT2 film response is nearly energy independent in the range of photon energy from 6 MV down to 22 keV [19,20], the dose response calibration of the film was carried out in a 6 MV photon beam produced by a medical linear accelerator (Siemens Primus M) in the dose range of 25—700 cGy. For this purpose, film samples of size 2.0×2.0 cm^2 were irradiated in a 10×10 cm^2 field of the accelerator by positioning them at 10 cm depth in a PMMA phantom of size $30 \times 30 \times 30$ cm^3. A set of un-irradiated film samples (background film samples) was also stored along with the irradiated film samples to account for the effect of variation in environmental conditions on the films. The OD of the background film samples was subtracted from the OD of the irradiated film to determine the net OD. Each film sample was scanned in landscape orientation and in red color channel mode of the Epson scanner. The optical density (OD) of each pixel in the central 1.0×1.0 cm^2 region of the film was measured and the mean optical density (MOD) was then calculated for each calibration film. A calibration curve between MOD and corresponding dose for the EBT2 film was plotted and a fit equation was obtained for subsequent determination of the absorbed dose from the measured OD.

Experimental set-up

To facilitate the comparison of TPS calculated and experimentally measured dose distributions, two anatomic phantoms were designed and fabricated locally by using a tissue equivalent alloy of wax and paraffin mixture. The