VALIDATING THE POTENTIAL-USEFULNESS OF THE ArcCHECK® DETECTOR TO VERIFY PLANNED BRACHYTHERAPY TREATMENT*

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Planned treatment verification procedures were created to ensure safety and effectiveness of radiotherapy. In brachytherapy, however, the verification procedure is methodologically complicated due to difficulties in measuring dose distribution around a radiation source placed inside the irradiated object. To address this problem, particularly as more complicate brachytherapy procedures are contemplated, we attempted to validate the potential usefulness of ArcCHECK® detector for direct verification of a brachytherapy treatment plan. A simple treatment plan was created for a specially-designed phantom which produced 2D dose distribution map on the phantom's surface. As a result, 2D map of dose distribution on phantom's surface. Subsequently, a Monte Carlo simulation of the experimental treatment plan was performed for comparison with measured data. This simulation used the EGS_brachy module, which is a part of the EGS_nrc Monte Carlo code. Measuring dose distribution using ArcCHECK® was a first step in a validation procedure. Next steps will include comparisons of measurement results with data exported from the treatment planning system (TPS), a further Monte Carlo Simulation and radiochromic film. The measurement described here provided qualitative indication of potential effectiveness of presented approach. Combined comparisons of ArcCHECK® measurement with other methods of validation of dose distribution should provide sufficient grounds to assess the device's value in verification procedure.

1. Introduction

Radiotherapy is one of the main methods of oncological treatment, alongside and often in combination with surgery and chemotherapy. However,

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radiotherapy carries some risk of specific side-effects. To minimize this risk, the impact of planned treatment must be accurately verified. Verification of planned radiotherapy treatment in oncology is a routine clinical practice. However, while verification of risk is relatively easy and straightforward in External Beam Radiation Therapy (EBRT), verification in brachytherapy, where the source of radiation is implanted within or adjacent to tumors, is very problematic. The problem arises because there is no way to directly measure the dose distribution from a brachytherapy seed. Due to this difficulty, the verification procedures in brachytherapy are not a common practice and a completely reliable procedure does not actually exist. This does not mean that brachytherapy is a more dangerous treatment than EBRT. Because the implantation of a radiation source in the treated area is highly consistent with the conditions were foreseen in the Treatment Planning System (TPS) and the dose gradient around brachytherapy seeds is much stronger than with an accelerator beam, permitting dose distributions that are almost perfectly conformal. However, as the applications of brachytherapy are extended, and the procedure is used in more complicated cases than previously, the need for a stronger verification method is growing. This paper proposed a brachytherapy verification method using the ArcCHECK® detector.

2. Materials and methods

ArcCHECK® by the Sun Nuclear Corporation is a 3D array of radiation detectors. The device is a cylindrical water-equivalent phantom with an array of 1386 SunPoint® diode detectors, arranged in a spiral pattern, with 10 mm sensor spacing [1]. The center of the phantom, a cylindrical cavity with 15 cm diameter, is designed to accommodate various accessories; in this study, a homogeneous PMMA phantom, BrachyPlug, was fitted to conform with to the ArcCHECK® internal space. The assembled experimental setup is shown in Fig. 1.

The experimental treatment plan for phantom irradiation was prepared in an Elekta Oncentra Brachy® treatment planning system. This plan included 120 source stop positions, 20 for each of 6 channels along the edge of phantom. The unit used in the plan was an Elekta microSelectron v3 with 192-Ir-mHDR-v2 seed. Dose distribution planned in TPS assumed a dose of 1 Gy on the nearest line of detectors. Step length between source stop positions was set at 0.25 cm, making 4.75 cm of total active length in each channel. Source activity on the day of experiment was 10.595 Ci. Stopping time in each position, as calculated in TPS, was 2.7 s, with a total duration of irradiation of 324 s. Dose distribution in one transversal plane, obtained in TPS is shown in Fig. 2.
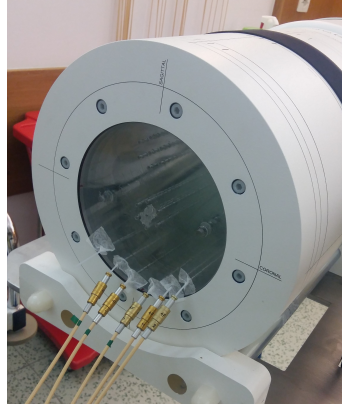
Fig. 1. Experimental setup assembled for dose distribution measurement. The ArcCHECK® detector with phantom BrachyPlug located inside. There are also shown catheters connected with brachytherapy afterloading unit (out of picture).
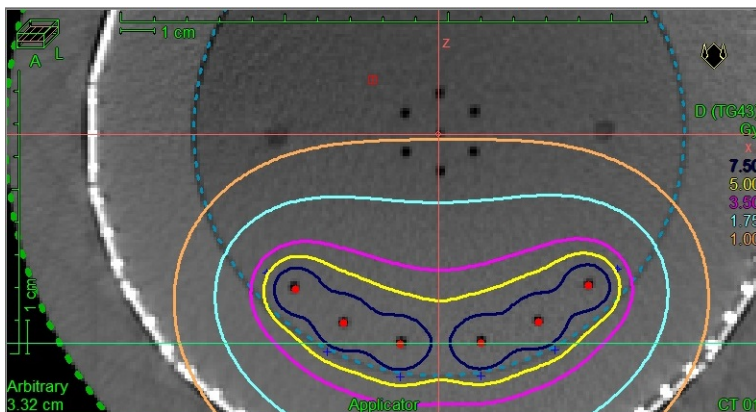

Fig. 2. (Color online) Fragment of Oncentra Brachy® TPS window. Picture shows dose distribution in transversal plane of phantom. Channels with planned source positions are marked with white/red dots.

A Monte Carlo simulation of the described treatment plan was also performed. The simulation was performed using EGS_brachy, a part of EGS_nrc code, that is designed for brachytherapy applications [2, 3]. The PMMA phantom was reconstructed in detail and source stop positions were also implemented. The spectrum of 192-Ir isotope is complicated [4, 5], which meant that an approximation based on the strongest radiation line about 380 keV was unsatisfactory. However, the EGS_brachy code provides a library of spectrum data for isotopes most often used in brachytherapy, including 192-Ir. The most general expression for the dose calculation in

EGS_brachy code is [2]

$$D^j = K_{\mathrm{col}}^j = \frac{\sum_i E_i t_i \left(\frac{\mu}{\rho}\right)_i}{V_j},$$

where D^j and K_{col}^j are, respectively, dose and collision kerma in j^{th} voxel, E_i is an energy of ith photon crossing the voxel, t_i is tracklength of that photon, $\left(\frac{\rho}{\mu}\right)$ is the mass energy absorption coefficient for energy E_i, and V_j is the volume of the voxel. The simulation was run in a superposition mode. In this mode, only one source is active at a time, exactly as it occures in HDR brachytherapy. This run mode is the most suitable for HDR simulations, in which there is only one active source in channel at each moment.

3. Results

The experimental treatment plan described in Section 2 was realized in BrachyPlug phantom, placed inside the ArcCHECK® detector (experimental setup — see Fig. 1). The results of measurements done by ArcCHECK® for the prepared treatment plan are shown in Fig. 3.
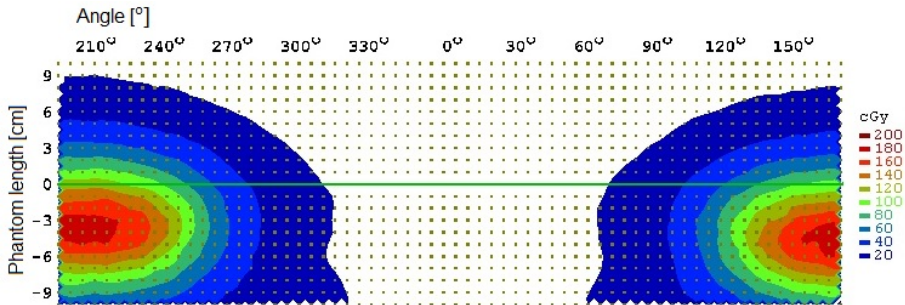

Fig. 3. Result of measurement of dose distribution for planned treatment scheme.

ArcCHECK® measurement results are displayed in a firmware application. Plots are in the form of a 2D map of dose distribution on the detector's surface. A rectangular map is obtained as a result of unrolling the cylindrical surface on which the diode detectors are located. The vertical axis indicates the phantom length, along its symmetry axis. The horizontal axis shows the angle between the vertical radius of the detector cylinder and a second radius pointing a different other direction similar to the hands of a clock, where one hand is fixed at 12 and the second may rotate freely. Therefore, the map in Fig. 3 shows a projection of the dose distribution from the cylindrical surface of detector on the two-dimensional plane: angle-phantom

length. Color codes provide information about the dose at a point on the detector surface. The obtained dose distribution reproduces the dose pattern that was planned in TPS. The high-dose area on the left- and right-hand side of Fig. 3, reflects the dose measured by detector diodes placed closest to the sources (compared with Fig. 2). Due to the corrections used, which are appropriate for MeV X-ray accelerator beas, the measured absolute dose amount is different from the planned one. Distributions of relative doses, planned and measured, were comparable, however. Using the DTA [6] comparison parameter, with 5 mm in distance and 5% in dose value acceptance criteria, 50.8% pixels meet the criterion.

4. Conclusions

The potential-usefulness of ArcCHECK® detector to verify brachytherapy may occur primarily in special cases: particularly difficult localization or irregular shape of tumor or closeness of critical organs. Moreover, new applications of brachytherapy extending its applicability can be checked *a priori*. ArcCHECK® is a device specifically designed for QA measurements in EBRT, which raises some complications when it is applied in brachytherapy. One problem is the inconsistency between EBRT treatment plans and brachytherapy ones. The ArcCHECK® software unrolls 3D dose distribution around isocenter point, but as the isocenter is not defined in brachytherapy, it is necessary to find a way to adapt planned brachytherapy dose distributions to the ArcCHECK® software with information about isocenter position. This way, brachytherapy dose distributions can be unrolled properly and compared with the planned dose distributions. The solution of this problem may be to first import brachytherapy plan to a TPS for accelerator radiotherapy, define the isocenter, and then return to the ArcCHECK® software with a plan that contains required geometry information. Another issue is related to the calibration of diode detectors. As a device intended for measuring accelerator beams, the ArcCHECK® detector is calibrated for MeV beam energies. Absolute dose measurements require calibration of the detector on 192-Ir energy. At this stage, we can only show qualitative data on the potential usefulness of ArcCHECK® to verify brachytherapy treatment. Our initial qualitative findings suggest that this detector may be relevant in brachytherapy applications. We believe this justifies obtaining more precise, qualitative information based on further research, including additional measurements, the use of radiochromic films, dose distribution comparisons, and calibration of detectors.

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