Dose control in treatment plans, for the I-125 sources implantation procedure of prostate gland ultraLDR brachytherapy

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Abstract

The study presents aspects of dose control in treatment plans for ultra-low dose brachytherapy (ultraLDR BRT) with the use of permanent I-125 isotope implants. A review of selected solutions of the dose distributions calculations and the quality control elements was performed and the workflow for the implantation of Eckert & Ziegler BEBIG GmbH type I25.S061 to the prostate at the Radiotherapy Center in Gorzów Wielkopolski (OR GW) was presented. A retrospective comparative analysis of point doses calculations for pre-plans created before implantation using the VariSeed 9.0 (Varian) and RadCalc (LAP) systems for 65 patients was also conducted.

Keywords: brachytherapy, ultraLDR, dose calculations, quality control

Introduction

According to data presented by the National Cancer Registry in Poland, in the years 2000-2021 approximately 95,000 patients died from prostate cancer [1]. The latest available data for 2022, presented by the International Agency for Research on Cancer at the World Health Organization, indicates that this disease is the second most common cancer among men worldwide and the fifth leading cause of cancer-related deaths [2].

There are various treatment options for prostate cancer, including several methods of radiotherapy: external beam radiation therapy (EBRT) and brachytherapy, which can be performed with either high-dose rate brachytherapy (HDR BRT) or low or ultra-low dose rate brachytherapy (uLDR BRT). Brachytherapy involves the insertion of radioactive sources into the prostate, where they remain for a specified period in order to affect the targeted area. Regarding the dose rate of the sources used, the definition indicates that in HDR, the dose rate exceeds 12 Gy/h, while in case of uLDR, it ranges from 0.01 to 0.3 Gy/h [3]. The procedure for delivering radiation in the case of uLDR BRT most commonly involves the placement of permanent radioactive implants in the form of seeds. This method is used, among other applications, in the radiotherapy of breast cancer, ocular tumors, and prostate cancer. The most commonly used isotopes in modern uLDR BRT include I-125, Pd-103, and Cs-131, while isotopes such as Rn-222 and Au-198 were or still are used in classic treatments [3]. In the case of prostate cancer, brachytherapy based on the application of permanent implants is primarily performed in the early stages of the disease [4], and centers conducting uLDR BRT in Poland implant seeds containing the I-125 isotope.

Dose Calculation in uLDR Brachytherapy

Similar to the dose calculations performed for HDR BRT, the most used formalism is presented in the report by Task Group 43 of the American Association of Physicists in Medicine (AAPM TG-43). Parameters such as dose rate, radial function, and anisotropy describe the full two-dimensional dose distribution in the transverse plane of the source. In the context of calculations for uLDR BRT, the AAPM TG-43 protocol includes dosimetric parameters for two types of I-125 implants obtained

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from measurements in water, as well as the Pd-103 source [5, 6]. Point models used in uLDR, which describe the dose distribution from a single seed, assume that the radioactive source is in a homogeneous water-density environment, while the effects of scattering and attenuation of radiation are neglected. Calculations based on a water environment do not realistically replicate phenomena occurring in volumes with a heterogeneous composition.

The AAPM-ESTRO-ABG TG-186 report, which recommends performing dose calculations in brachytherapy while accounting for tissue inhomogeneity, is also rarely used [7]. The accuracy of clinical dose calculations can be improved by application of Monte Carlo (MC) simulation-based models, which account for realistic effects in tissues and seed capsules [8, 9]. In a study by DeMarco et al. [10], the anisotropy and radial functions obtained from calculations using the MCNP4B code were compared with the data from the TG-43 report for two types of I-125 sources. It was shown that the MC code is a suitable tool for modeling I-125 seeds, and the data from these calculations matched the TG-43 formalism within 6% for all calculation points. Simulations of the isodose distribution for homogeneous and heterogeneous volumes were also performed, with the isodose corresponding to a 5.6% lower volume in the case of calculations using tissue composition. Another study [11] presents a comparison of dose distributions between data obtained using MC simulations and from a commercially available treatment planning system. It was shown that the clinically used system overestimates doses for isodoses higher than 100% – isodoses of 150% and 200%, which were characterized by lower volumes in MC calculations than those in the used software. A 5% difference in doses was also observed in case of data slices in the urethra. These discrepancies arise from the excessive simplification of the source model and the failure to account for certain physical interactions between neighboring implants. Efforts are also being made to link the calculated dose distributions with radiobiological models which determine the treatment efficacy, however such calculations are not currently practiced in routine work [12]. The authors of another study [13] compared uLDR BRT prostate treatment plans obtained using conventional planning and those created through the application of inverse optimization, which required the definition of biological goals, including Tumor Control Probability (TCP). Biological optimization considered the uneven distribution of cancer cell density in the prostate based on known and predicted tumor locations. The most striking findings of this work were the achievement of a lower dose to the urethra in the radiobiological method while maintaining high TCP values and reducing the number of seeds needed by approximately 10.

Quality Control Elements of Seed Implantation Process

The tasks of medical physicists during the ionizing radiation treatment process [14-15] are defined by the Polish law. The Minister of Health's Regulation from December 12, 2022, regarding operational tests of radiological devices and auxiliary equipment, mandates that an image grid on the ultrasound screen with a template grid must be checked every three months, according to the manufacturer's recommendations. Before each application, the radiation contamination meter and handheld radiation monitor must be checked for functionality. Another control element involves assessment of the deviation of the measured source strength from the value provided by the manufacturer for a single source within a batch of sources – the difference should not exceed ±5%. According to the definition in the regulation, the source strength for photon-emitting sources in brachytherapy is the value provided in the source certificate, often expressed as the reference air kerma rate or the source activity. The four mandatory tests listed above for seed implantation are included in Annex 1, item III.4.4. Frequency of performance and tolerances for physical and dosimetric parameters when using permanent implants. There are many international documents which describe the quality control principles and good practices for conducting brachytherapy procedures or procedures specifically related to LDR BRT treatments [16-18]. One of the main issues presented in these recommendations is associated with measurements conducted in a well chamber. For this task, it is important to use a device with a dedicated insert for the implant – a holder that should be characterized by the appropriate physical density so that it does not interfere with the measurement accuracy and allows for reproducibility of the source position [17]. The literature describes attempts to evaluate whether a universal dose calibrator used in nuclear medicine could potentially serve as a substitute for a dedicated well chamber for measuring the activity of I-125 radioactive sources [19]. The accuracy, precision, and repeatability of the dose calibrator's operation were tested, and the authors of this work concluded that a dose calibrator with a different geometry can also be used to verify the activity of I-125 seeds. An approach used in other countries is to measure the activity of the majority or all the seeds used, individually, to eliminate empty or incorrectly manufactured seeds. However, this approach introduces the problem of maintaining the sterility of the sources before application to the patient and results in prolonged procedure time, which potentially increases radiation exposure for the staff. However, methods using X-ray radiation are proposed, which preserve the sterile environment and control sources in batches of several pieces [20]. In the context of radiation protection, an interesting issue is the assessment of the radiation emitted by a patient who has undergone seed implantation. Measuring this parameter is a part of a broader quality control and radiological safety assessment, and it allows for the evaluation of the radiation exposure risk to individuals near patients with permanently implanted sources. Research has been conducted using Monte Carlo simulations to estimate the dose around the patient's body after performing uLDR BRT prostate treatment with I-125 seeds [21]. Another task performed as part of the patient environment control is the measurement of the activity of urine excreted by the patient, in order to detect any undesirable migration of implants outside the prostate area.

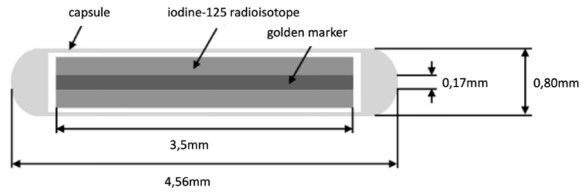

Fig. 1 *Longitudinal cross-sectional diagram of a single I-125 permanent implant capsule placed on a biodegradable thread*
Source: Author's own work.

Example Procedure Scheme

The following procedure for implanting I-125 sources in the form of seeds for patients with prostate cancer is performed at the Radiotherapy Center in Gorzów Wielkopolski (OR GW). The organ is to receive a therapeutic dose of 145 Gy. Dose calculations are carried out using the Vari Seed 9.0 (Varian) and RadCalc 7.3 (LAP) software.

The iodine-125 radioisotope, which emits radiation with a maximum energy of approximately 35 keV, is encapsulated together with a marker that enables localization during imaging. OR GW utilizes the IsoSeed I25.S06 type, manufactured by Bebig GmbH (Berlin, Germany). The seed has a cylindrical shape, with a total length of 4.56 mm and an outer diameter of 0.8 mm. The capsule includes a gold rod measuring 3.5 mm in length and 0.17 mm in diameter, along with the radioactive substance in the form of silver iodide.

A schematic cross-section of the seed is shown in Figure 1.

The seeds are placed on a biodegradable thread at 1 cm intervals between the centers of consecutive sources. The seed strand is wound on a spool and stored in a protective safe, which can hold up to 70 units [22]. The sources are applied in specific quantities under ultrasound imaging guidance using dedicated needles and a localization template, e.g. during HDR BRT. Before implantation into the prostate, a treatment plan (preplan) is prepared, specifying the implant positions. This provides information on how to separate the seeds from the thread using a designated cutter, which also facilitates the transfer of an appropriate number of implants into the needle. At least one seed from each cassette is used for a legally required measurement. This procedure is performed using a measurement set consisting of a SOURCECHECK 4π (PTW) chamber with a funnel-shaped insert and a UNIDOS Romeo (PTW) electrometer. The differences in measured values obtained at OR GW did not exceed ±5% of the values specified in the manufacturer's certificate. The images taken during the I-125 implantation procedure are presented in Figure 2.

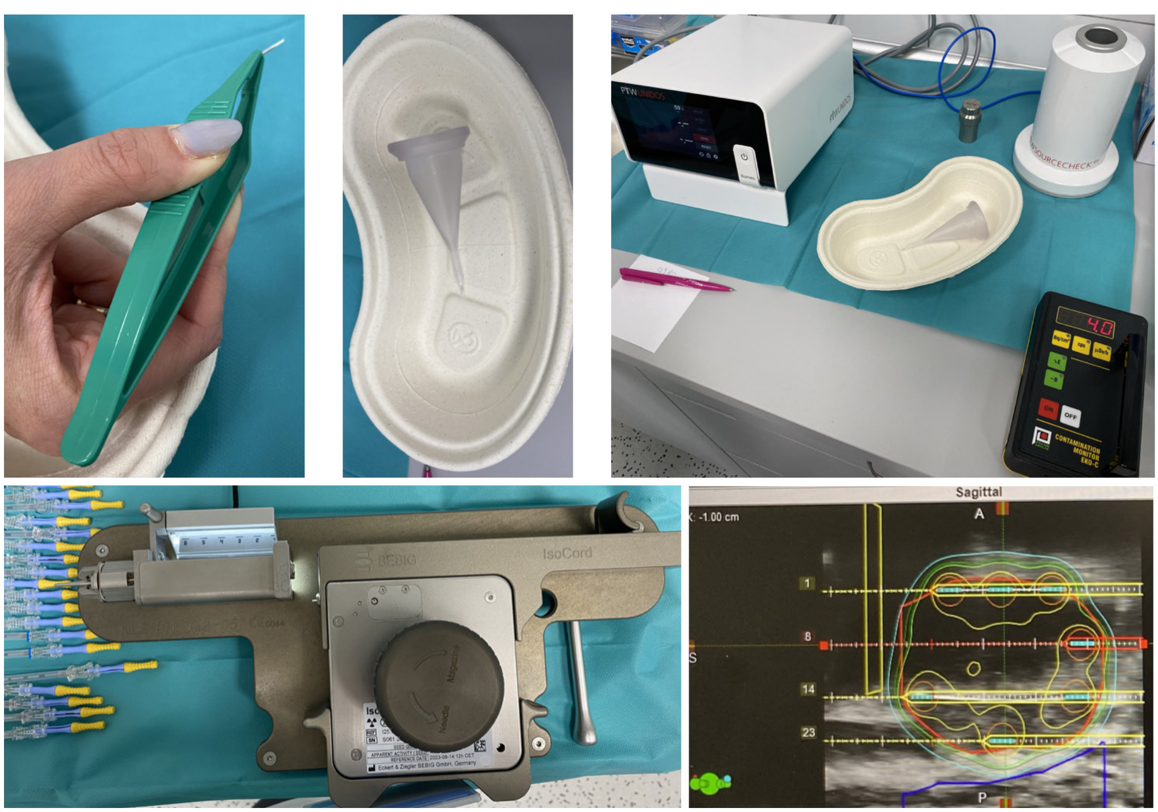

Fig. 2 *From the left: implant designated for dose rate measurement, adapter for the well chamber, measurement set – chamber with an electrometer, protective container for unused sources, and surface contamination meter. Below, from the left: needle loading station with a cassette containing implants and an example of the dose distribution from the treatment planning system in a lateral cross-section*
Source: Author's own work.

Additionally, a verification of the preplan calculations is performed by comparing the point doses calculated by the clinically used VariSeed system with calculations performed using the independent RadCalc software.

On the first night after the procedure, the patient's urine is collected and stored for measurement using a contamination meter to identify any potential expulsion of implants. Furthermore, on the day following implantation and at predetermined time intervals, pelvic computed tomography (CT) imaging is conducted to verify the actual placement of the iodine seeds.

Dose Verification Through Independent Calculations:

In accordance with the Regulation of the Minister of Health from January 11, 2023, on the conditions for the safe use of ionizing radiation for all types of medical exposure, one of the requirements is the verification of the treatment plan dose through independent calculations.

Since June 2023, more than 60 I-125 implantation procedures have been performed at OR GW. The dose analysis from both systems includes 65 cases. RadCalc software version 7.3 offers a set of calculation models for isotopes used in radiotherapy, including both linear and point sources. For verification, the point source template named I-125 Bard (Point) was selected. The implemented functions were compared between the treatment planning system and the independent software.

The obtained dose differences were summarized at a verification point ensuring a uniform isodose distribution, which was at the reference cross-section in the urethra. The median dose difference at the verification point was 1.10%, with an average of 1.08% and a standard deviation of 0.11%. The minimum and maximum values were 0.90% and 1.50%, respectively.

The percentage differences between the dose values obtained in the VariSeed treatment planning system and the calculations in RadCalc for each patient are presented in Figure 3. The differences in calculations remain low because both systems perform calculations using the TG-43 formalism.

Summary

Dose control is a crucial aspect of procedures which involve ionizing radiation – it ensures safety for both the patient and the staff. Performing legally required tests and applying best practice recommendations are the responsibilities of medical physicists and the entire team involved in brachytherapy procedures.

The currently used calculation programs provide the opportunity for verification through independent dose calculations and can be successfully applied in uLDR BRT for prostate cancer, as they do not significantly extend the duration of the procedure. However, it remains essential to perform measurements in order to verify the dose rate of the sources used.

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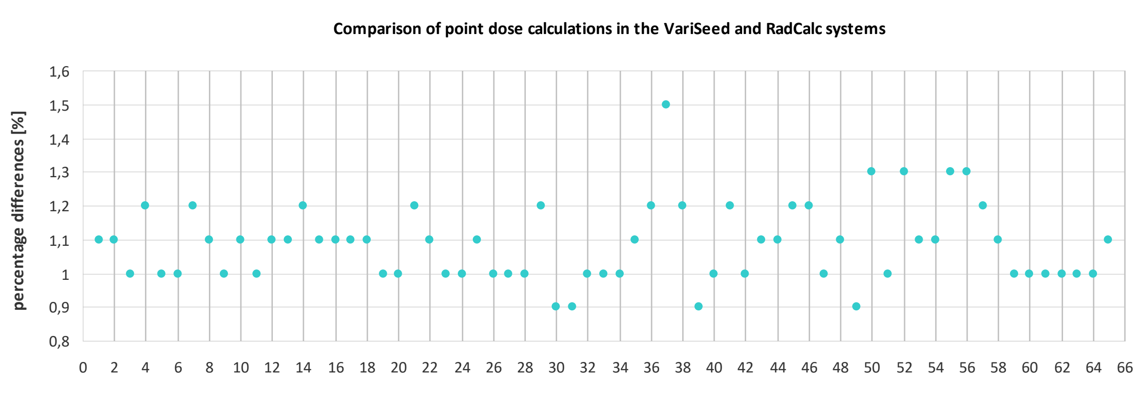

__Fig. 3__ Percentage differences in point doses calculated using the VariSeed 9.0 and RadCalc 7.3 systems
Source: Author's own work.

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