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STEREOTACTIC BODY RADIATION THERAPY – DOSIMETRY AND MECHANICAL PREPARATION OF LINEAR ACCELERATOR

M. Szymański[1,2], M. Bojarojć[1*], A. Jabłońska[1], B. Kuśmierska-Piątek[1]

[1]Masovian Oncology Hospital in Wieliszew, Warsaw, Poland
[2]Maria Sklodowska-Curie National Research Institute of Oncology, Warsaw, Poland

Abstract. *The aim of this study is to emphasize the importance of proper dosimetric and mechanical preparation of the linear accelerator and to highlight the significance of this step in ensuring the efficacy and safety of stereotactic body radiation therapy (SBRT). Performance verification of two Varian VitalBeam linear accelerators was executed in order to monitor the output consistency, MLC repeatability and radiation isocenter location and size. Dose output consistency measurements were conducted using phantoms and dosimetric equipment from PTW. The analysis of MLC positioning tests, isocenter size and location were performed by in-house scripts based on pylinac tools. These tests were conducted on a weekly basis. Evaluation of the results of tests performed over a 90-week period showed a positive trend in output consistency. However, no discernible trend or pattern was observed in the other tests. In conclusion, the authors suggest that performing dosimetric and mechanical checks on the linear accelerator before conducting SBRT treatment is an effective way to maintain a safe treatment environment.*

Keywords: *dosimetry, quality assurance (QA), radiation safety, stereotactic body radiation therapy (SBRT)*

1. Introduction

External beam radiation therapy is a commonly used method for treating oncology patients. Radiation doses are delivered to cancerous cells in fractions and while the majority of patients undergoing radiation therapy are treated with the conventional fractionation, an increasing number of patients are now being treated with a specialized radiotherapy technique called stereotactic body radiation therapy (SBRT) [1] . SBRT is equally valid for both radical and palliative treatment of primary and secondary malignancies [2]. In this treatment method a high dose of radiation is delivered to a tumor of small volume in one or several fractions over a short period of time. Consequently, the fractional dose is correspondingly higher compared to conventional fractionation [3]. The unique characteristics of SBRT tightly link treatment outcomes with the accuracy of both the delivered dose and the spatial consistency of the delivered and planned dose distribution. This underscores the necessity for heightened attention, not only to the patient, but also to the linear accelerator, which must provide the utmost precision in dosimetry and geometry.

The primary focus of medical physicists during the SBRT therapy preparation process for each patient is centered on the creation and dosimetric assessment of a treatment plan calculated in a treatment planning system. Another key role of physicists, being subject of this study, is mechanical and dosimetric preparation of the linear accelerator.

Mechanical and dosimetric checks include a variety of tests mandated by national law in Poland, alongside additional tests performed in accordance with the manufacturer's procedures, local quality assurance protocol and widely accepted best practices. The aim of this research is to establish a comprehensive set of tests that ensures a high level of certainty regarding the accurate and consistent operation of the accelerator. Moreover, these tests should be feasible to perform on the same day right before the treatment session.

Until December 2022 [4], specific legal requirements outlining the linear accelerator preparation process for SBRT procedures were not established in Poland. The registry of obligatory tests for linear accelerators used in radiotherapy was well-defined, however there was no explicit list of mandatory tests to be performed specifically before each SBRT treatment session. While a referenced SBRT procedure description published by the Polish Ministry of Health in 2014 recommended focusing on testing the radiation isocenter [5], it did not provide desined frequency for performing this test. Additionally, although importance of the radiation isocenter test is unquestionable, relying solely on this test certainly does not seem sufficient in adequately preparing the linear accelerator for SBRT treatment.

Participating in an external Level III dosimetric audit appears to be the most comprehensive and independent approach for evaluating the entire treatment process simultaneously. This type of assessment holds substantial recognition from international organizations such as the International Atomic Energy Agency (IAEA) [6] and the World Health Organization (WHO) [7]. Initially carried out as pilot trials conducted using conventional linear accelerators, there are even suggestions to expand these audits to cover accelerators explicitly engineered for SBRT therapy, like the CyberKnife system [8], [9]. The authors find participation in external dosimetric

*E-mail of the corresponding author – magda.bojarojc@gmail.com

audit as an essential tool for assessing the accuracy of both prepared and conducted radiotherapy. However, due to its time-consuming nature, performing such audits is only required periodically and is not being considered as a daily test.

Therefore, taking into account the pressing necessity to establish a comprehensive check-up agenda to ensure confident and safe SBRT treatment, this study has chosen to analyze a set of tests capable of assessing the precision of therapy.

In order to ensure safety of patients undergoing SBRT treatment and minimize clinical downtime of the accelerator, it seems to be essential to perform certain checks and verifications. Due to the high radiation dose involved, it may be necessary to assess the stability performance of the accelerator before irradiating patients. This step could crucial for maintaining a safe treatment environment.

Given the small size of the tumor and the requirement for precise therapy, it is vital to verify the alignment and size of the radiological isocenter [10]. This can ensure accurate radiation delivery and provide the desired treatment outcomes. By confirming the compatibility of the isocenter's position and size, the highest level of precision can be achieved.

Although not considered mandatory, performing tests to evaluate the functionality of the MLC should be recommended. Despite the brief time required to conduct the test, its inclusion in the quality assurance process can further enhance the overall safety and accuracy of the treatment.

These three tests may be a basic and essential set when preparing the linear accelerator for SBRT treatment.

2. Materials and methods

For the purpose of this study a performance verification was analyzed on two Vital Beam accelerators manufactured by Varian, installed at the Masovian Oncology Hospital in Wieliszew. In compliance with Polish legal requirements, the output consistency check is required to be performed at least once a week, while the test of isocenter location and size every six months. Although multileaf collimator (MLC) performance check is not obligated, it was included as a part of a weekly mechanical check of the linear accelerator. Location and size of radiological isocenter, as well as coincidence of radiological and imaging isocenter, was also assessed on a weekly basis.

To evaluate the dosimetric performance of the accelerators, a series of measurements were conducted. Output consistency was measured using a slab PMMA phantom with the TM30013 ionization chamber, which was connected to the Unidos Webline T10021 electrometer. The dosimetry kit possessed a valid calibration certificate issued by the Secondary Standard Dosimetry Laboratory (SSDL) in Poland. The PMMA phantom was positioned in accordance with locally established protocols, ensuring accurate alignment with the beam axis of the accelerator. The electrometer with the ionization chamber was utilized to measure the dose delivered to the phantom for field size 10 × 10 cm2 at the nominal source to axis distance (SAD) of 100 cm. Dose measurement was corrected to

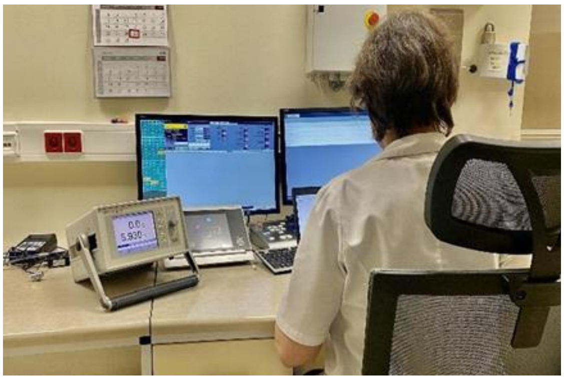

Figure 1. Output consistency check - control room of the linear accelerator

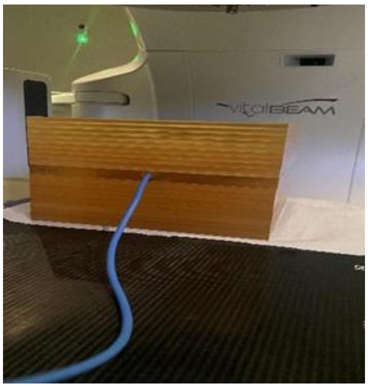

Figure 2. PMMA phantom with TM30013 ionization chamber inserted into a holder

account for the temperature and atmospheric pressure influences and expressed in cGy/100MU and the tolerance was set to +/-2%.

Location and size of the radiological isocenter were checked using an ISOBall phantom. To evaluate the positional accuracy of the radiological isocenter, specific reference points on the phantom were marked and images were acquired using megavoltage imaging systems integrated into the accelerators. The obtained images were subsequently analyzed with dedicated software to detect any deviations from the desired isocenter position. Aforementioned equipment was produced by PTW Freiburg company. To perform the check, DICOM files representing a digital record of data generated during the exposure of test fields to an electronic imaging portal (EPID) were analyzed. The results were expressed in mm with the tolerance limit of 2mm.

To evaluate the accuracy and reproducibility of the MLC leaf motion, a series of dynamic Picket Fence tests were conducted, which included specific dynamic measurement to assess MLC performance during simultaneous gantry rotation. The evaluation of MLC leaf motion was based on comparing the measured positions to the expected positions (maximum and median leaf position error, mean distance between pickets – all expressed in mm) [11]. Notably, machine log data was not utilized during the analysis of measured data.

All measurements and analyses were performed following established protocols and guidelines provided by IAEA in the TRS398 report [12] and the equipment manufacturers, as well as relevant international standards and local procedures. Any deviations or discrepancies observed during the performance verification process were documented and appropriate corrective actions were promptly implemented as necessary.

Figure 3. Set-up of ISOBall phantom in accordance with isocenter pointed by laser system

3. Results

A total of 90 measurements were conducted for each parameter. These measurements were taken at regular intervals, once a week.

The results presented on the graphs for each accelerator include measurements of output stability [cGy/100MU], the size of radiological isocenter [mm] and MLC performance check [mm]. The tolerance limits for output consistency and the isocenter size are in accordance with acceptance limits defined in local procedures.

Notable trends were only evident in the output consistency check which showed a gradual increase over time. The variation of beam output in time can be noticed in other Varian accelerators with mean value of +1,22%/year [13], however the results presented above show significantly faster increase up to +1%/6 weeks.

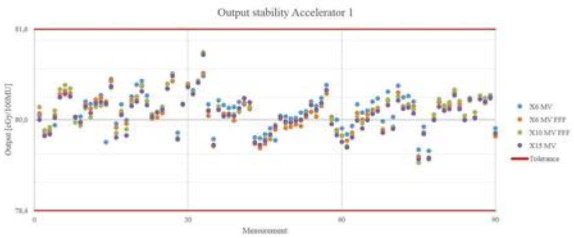

Figure 4. Output stability results for accelerator 1

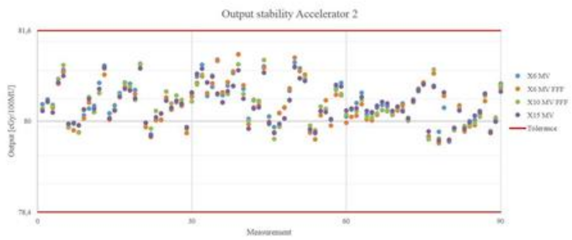

Figure 5. Output stability results for accelerator 2

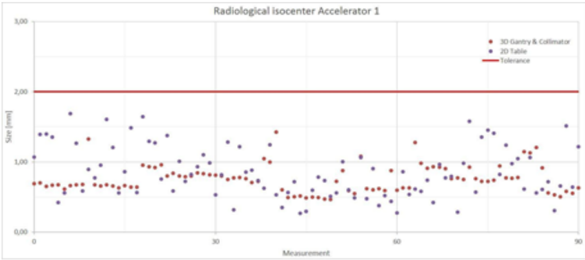

Figure 6. Size of radiological isocenter for accelerator 1

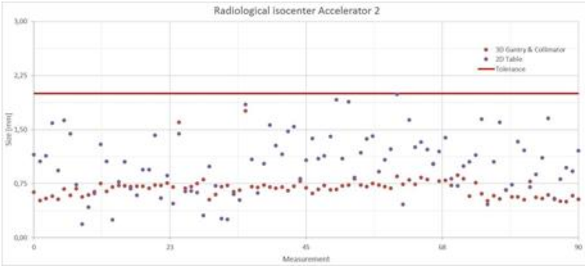

Figure 7. Size of radiological isocenter for accelerator 2

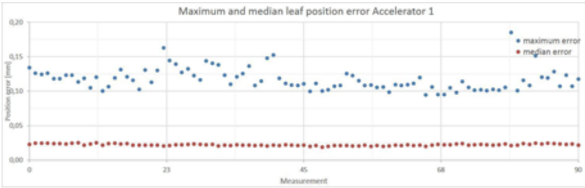

Figure 8. Values of maximum and median leaf position error for accelerator 1

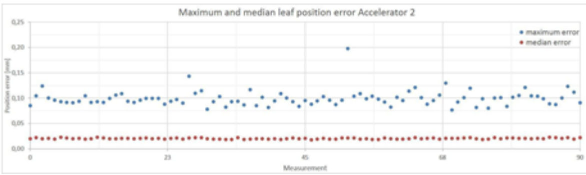

Figure 9. Values of maximum and median leaf position error for accelerator 2

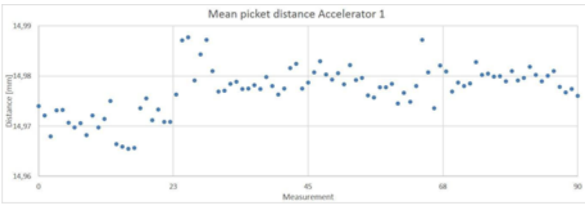

Figure 10. Values of mean picket distance for accelerator 1

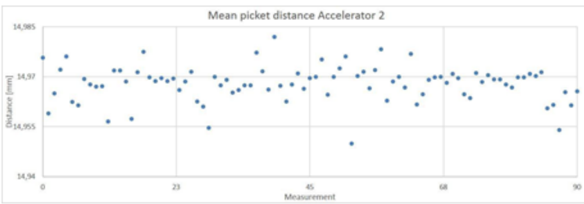

Figure 11. Values of mean picket distance for accelerator 2

This may suggest rather low stability of accelerators and leads to more frequent output calibration procedure performance.

The results of isocenter and MLC performance checks displayed no discernible trends or patterns. While the values of 3D Gantry & Collimator isocenter size seem to be more stable in time, the 2D Table isocenter size is seen to be more variable with relatively larger differences between each two measurements. A similar trend was observed by Szweda et al. [14] and explained as related to the mobility of the phantom during couch movement while performing the test.

Furthermore, no significant deviations from the expected values or established tolerances were noted.

4. Conclusion

Proper clinical implementation of SBRT technique requires highly skilled medical professionals, perfect cooperation between medical doctors, dosimetrists and radiation therapists.

By incorporating into clinical workflow these necessary procedures, which are measurements of output consistency, radiological isocenter size and MLC performance, the safety of patients undergoing SBRT treatments can be effectively maintained while minimizing disruptions to the clinical operation of the accelerator. Ongoing quality assurance measures mentioned above contribute to the overall quality and precision of SBRT treatments. This optimized approach ultimately leads to improved patient outcomes and ensures the highest standard of care.

Please note that it is important to consult and adhere to local radiation safety guidelines and protocols for specific requirements related to SBRT treatments and quality assurance procedures.

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