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Increasing The Accuracy Of Dose Delivery To CTV During PBS Proton Therapy

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Currently, the proton therapy (PT) method, which uses a thin scanning beam, is one of the most ef-fective and modern methods for creating a conformal (shape-matching with the tumor) distribution of the absorbed dose in the tumor. A highly conformal dose distribution is achieved by optimizing thou-sands of thin proton beams. In order to prevent the occurrence of clinically significant errors, increased requirements are placed on the accuracy of delivery of each individual thin beam.
The advantages provided by the Bragg peak allow for more accurate dose distribution, but also re-quire greater precision in patient positioning. Incorrect patient positioning during PT can lead to serious errors, including underexposure of tumors and overexposure to healthy tissue. To neutralize this effect, the concept used is to irradiate an area that exceeds the size of the subclinical spread of the tumor. The clinical volume of a tumor, including the microscopic spread of cancer cells around it, is called CTV. Planned target volume (PTV) is CTV plus some margin. It is assumed that some of the normal tissue surrounding the CTV within the irradiated area may be included in the irradiation to ensure adequate coverage of the target with a uniform dose, taking into account possible geometric uncertainties.
In radiotherapy, the presence of various inhomogeneities in the path of the proton beam (e.g., bone, lung, air cavities) can lead to a significant deterioration in the predictability of the final dose distribu-tion in the event of errors in beam delivery. Before each PT session, it is necessary to check the pa-tient's position using two orthogonal images and then evaluate the position correction. In the Russian Federation, standards for PTV margins for PT have not yet been established. Therefore, generally ac-cepted margins applied for photon therapy are used. Typically, the CTV-PTV margin ranges from 3 mm to 20 mm.
When comparing PT to conventional photon therapy, a different approach must be taken to deter-mine the margin between the CTV and PTV. Especially in the case of PT using PBS for fixed targets surrounded by bone structures, it is possible to determine a minimum margin that takes into account the accuracy of dose delivery of a particular PT system. There is no mention in the literature of meth-ods for assessing the accuracy of PT systems and the impact of the results of such assessment on the accuracy of radiation dose delivery to tumors of various locations.
The Proton Center of the Federal Scientific Clinical Center for Medical Radiology and Oncology of FMBA of Russia (FSCCRO of FMBA of Russia) uses the IBA Proteus Plus PT system, based on the IBA C235-V3 cyclotron. In 2011-2012, the cyclotron was assembled and tested at the Joint Institute for Nuclear Research in Dubna, then delivered to Dimitrovgrad. Given the characteristics of the system and the organization of clinical processes, the accuracy of dose delivery to the CTV can be influenced by various factors, such as radiation output, accuracy of narrow beam delivery, energy choice and col-linearity of X-ray and PT systems. To speed up the process of morning measurements (quality assur-ance QAs), a combination of the IBA LynxPT scintillation detector and the IBA Sphinx phantom was chosen, which made it possible to significantly reduce the time of daily morning QA checks from 2-2.5 hours to 20-30 minutes. This optimization increased efficiency in the use of clinical time and allowed additional patients to be treated, increasing PT center throughput capacity by 18%.
The dimensions of the CTV-PTV margins established by the FSCCRO of FMBA of Russia are based on clinical recommendations developed for the use of photon devices in radiation therapy, and are 3 mm for the case of intracranial tumors. However, to take into account errors in dose delivery to the CTV, it is necessary to calculate the minimum required CTV-PTV margin. This calculation requires analyzing the stability of the dosimetric parameters of the PT system, such as the constancy of the size and position of the narrow beam, the collinearity of the central axes of the proton and X-ray systems, as well as the stability of the energy selection system.
PT system parameters measurements were recorded in the IBA MyQA software database, including date and measured values. This data was exported into a spreadsheet format for further analysis. Daily morning checks of the PT system parameters were carried out over a period of 11 months. Measure-ments were taken at different gantry angles (0°, 90° or 270°) on weekdays. As a result, over three working weeks, 5 measurements were made at each gantry angle.

The position of the narrow beam was set to ±10% of the reference value to ensure a constant beam penumbra within 1 mm. The position of the narrow beam remained within ±1 mm throughout all meas-urements in both PT rooms. The average deviation of the narrow beam position from the reference val-ue did not exceed 0.4 mm. Analysis of the images obtained on the LynxPT screen as part of the morn-ing checks also showed that the fluctuations in the position of the narrow beam were insignificant. The range of deviations of all studied parameters of the PT system from the reference values remained within the limits recommended in TG-224.
There is no mention in the literature of methods for assessing the accuracy of PT systems and the impact of the results of such assessment on the accuracy of radiation dose delivery to tumors of various locations. Therefore, it was decided to adapt the well-known approach to calculating the margin to take into account geometric uncertainties to the results of an 11-month monitoring of the stability of the parameters of the PT system.
Errors in the lateral direction come from errors in narrow beam position and collinearity, and in the axial direction from errors in energy parameters. Based on the standard orientation of the patient on the treatment table, lateral errors in the X direction are used to calculate the margin in the head-foot direc-tion, and in the Y direction for left-right and abdomen-back. Axial errors are used to calculate the mar-gin along the beam axis. In the lateral directions relative to the beam axis, the calculated margin was 0.8 mm, along the beam axis –0.4 mm.
The calculated values represent the minimum indentations in the corresponding directions for plan-ning PT in the FSCCRO of FMBA of Russia. Their use, taking into account the accuracy of dose de-livery by the PT system, ensures CTV coverage of 95% of the prescribed dose. This is especially im-portant for stationary targets surrounded by inert structures, for example, for brain tumors, where in-trafractional movement of the target can be neglected.
After studying the methods for conducting morning QAs of the parameters of the PT system, the optimal set of parameters was determined that should be measured as part of the daily quality assur-ance program for the PT system IBA Proteus Plus, used in the Proton Center of the FSCCRO of FMBA of Russia.
The methodology for morning checks of the PT system parameters was optimized using the LynxPT+Sphinx complex, which led to a reduction in the time of inspections by 7.5 times and an in-crease in the throughput of the PT center by 18%. These tests include all recommended tests from TG-224 for PBS systems.
The constancy of the relative dosimetric parameters of the PT system affecting the calculation of the CTV-PTV margin was analyzed. Over nine months, no significant deviations from reference values exceeding acceptable limits were detected. The total mechanical error exceeded 1 mm in 1.3% of cases, the maximum value was 1.3 mm.
Using the approach known from the literature for calculating the CTV-PTV margin taking into ac-count the patient positioning error, the CTV-PTV margin was calculated taking into account the dose delivery error of the PT system. The obtained minimum margin values, taking into account the accuracy of dose delivery, can be applied both for single-field (0.8 mm in the lateral directions relative to the beam axis, 0.4 mm in the direction along the beam axis) and for multi-field (0.8 mm in all directions) irradiation. It is proposed to use this margin calculation method, which takes into account the accuracy of dose delivery by the PT system, in new PT centers.

Section

Applications of nuclear methods in science, technology, medicine and radioecology

Primary authors: KISELEV, Vasilii (FSCCRO of FMBA of Russia); CHERNYAEV, Alexander (Faculty of Physics M.V.Lomonosov Moscow State University); Dr UDALOV, Yurii (FSCCRO of FMBA of Russia); Dr BELIKHIN, Mikhail (P.N. Lebedev Physical Institute of the Russian Academy of Sciences); Mrs DEMIDOVA, Anna (FSCCRO of FMBA of Russia); Dr GRITSENKO, Sergey (FSCCRO of FMBA of Russia)

Presenter: KISELEV, Vasilii (FSCCRO of FMBA of Russia)

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