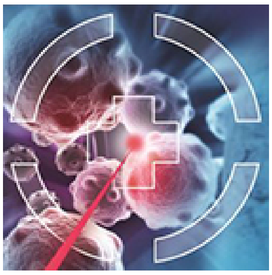

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Dosimetric commissioning of a pencil beam algorithm for the scanned carbon ion beam delivery system installed at MedAustron Ion Therapy Center.

Purpose: Since December 2016 at the MedAustron Ion Therapy center (MA) patients have been treated with protons. The synchrotron accelerator is also able to deliver carbon ions with energies between 120 and 402.8 MeV/u (ranges from 2.9 to 27 cm in water). In this work we report the results of dosimetric commissioning of the pencil beam algorithm PBv3.0 available in the treatment planning system (TPS) RayStation RSv8B (RaySearch Laboratories, RSL, Sweden) for a scanned carbon ion beam delivery in one fixed horizontal beamline at MA.

Materials and Methods: Measurements were performed with detectors and water phantoms positioned at different air gaps including cases with and without range shifter (RaShi). We introduced the ISD definition as the distance between the in-room isocenter and the detector/phantom surface with positive values for surfaces upstream of the isocenter (toward the nozzle) and negative values downstream of the isocenter. The validation of the PBv3.0 algorithm was done step by step by increasing the complexity of the tests. First, we evaluated the performance of the dose engine in reproducing dosimetric properties for the delivery of single static pencil beams (1D commissioning) and for a mono-energetic layer with multiple spots (2D commissioning). After that, the delivery of quasi-discrete scanned pencil beam for multiple energy layers to irradiate a 3D target was assessed (3D commissioning). In the first step, Integrated Radial Profiles as function of Depth (IRPDs) in water, lateral spot profiles in air and absorbed dose to water in reference conditions were measured. For the last step, test cases complexity was increased from the easier box-shaped fields in homogeneous phantoms to more complex clinical cases. For all the 1D-2D-3D tests, the same experimental setup was reproduced in the TPS. The IRPDs were measured in the water phantom. Measurements were carried out with a plane parallel ionization chamber PPIC (model 34070, sensitive diameter 81.6 mm, PTW- Freiburg) at ISD0cm (isocentric configuration) and at ISD50cm (non-isocentric configuration) for a sample of energies selected over the clinical range. Comparison between calculations and measurements was done in terms of physical range at 80% of the peak dose (R_{80}) and relative point-to-point dose deviations in percentage. The lateral spot profiles in air were acquired with a Lynx detector (IBA Dosimetry, Schwarzenbruck) at several ISDs (-20 cm, 0 cm, 20 cm, 30 cm, 40 cm, 50 cm, 58 cm) for different energies. Measurements and calculations were compared in terms of Full Width at Half Maximum (FWHM) in the two orthogonal planes. Beam model calibration in terms of absorbed dose to water were carried out at the center of mono-energetic layers with the PTW-34001 Roos type chamber positioned in water at the reference depths of 14 mm and at 75% of R_{80}. The relative deviations in percentage between the absorbed dose to water predicted by the TPS and the measured one were evaluated. Most of the treatment plans created for the validation of 3D delivery were optimized at ISD0cm and ISD50cm. Absolute doses were measured with 24 PinPoint ICs (PTW-31015) fixed to the 3D detector block holder in a MP3-P water phantom (PTW-Freiburg). The absorbed dose to water values were extracted from the TPS at the effective point of measurement of each PinPoint chamber and compared with the measured values. The agreement between the planned and the measured dose was evaluated based on the mean of the overall local or global (normalized to max dose per beam) deviations and the pass-rate of global deviations within 3 %, 5 % and 7 %.

Results: Relative dose difference between TPS calculated and measured IRPDs at ISD0cm shows an agreement within 1 % and within 5 % at ISD50cm with RaShi. The computed and measured R_{80} are in very good agreement within ± 0.1 mm. For lateral spot profiles in air the computed FWHM is within 0.3 mm or 5 % of the measured one at ISD0. Larger deviations in terms of FWHM within ±12 % were found at a reduced air gap (ISD 58cm). Measured and computed absorbed doses to water at the reference conditions agree within ±1.5 %. The 3D commissioning for simple boxes in water at ISD0cm shows a mean local dose difference within ±2 % that increase to ±4 % for deep seated targets. Similar behavior has been observed at ISD50cm. For box-like targets in presence of RaShi the mean global deviations are within ±1 %. Regarding the clinical cases for a temporal lobe sarcoma case, mean global dose deviations were within ±2 % for all the beams (see Figure 1).

Conclusion: Extensive TPS commissioning validation was done from April to June 2019 before starting treatment with carbon ions. Based on the positive results of the dosimetric commissioning the first patient has been safely treated with carbon ions at MA in July 2019. The described stepwise methodology is broadly applicable and the validation of different treatment plans gives an indication of capabilities and limitations of the PBv3.0 algorithm over the entire clinical range.

Figure 1. The mean of the global differences for all the eight beams composing the temporal lobe sarcoma patient plan.

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