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

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MedAustron Ion Therapy Center

Purpose

Figure 1. Layout of the MedAustron Ion Therapy Center, showing the MedAustron Particle Therapy Accelerator (MAPTA) components and the four Irradiation Rooms.

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 (carbon ions with energies between 120 and 402.8 MeV/u - ranges from 2.9 to 27 cm in water) installed in one fixed horizontal beamline (HBL) at MedAustron.

Materials & Methods

In RSv8B the carbon dose and RBE weighted dose calculation is based on the pencil beam dose algorithm. The dose for each voxel is evaluated performing a factorization of the dose to the lateral dose profile and the longitudinal, Integrated Radial Dose Profile as function of depth (IRDPs) components. The carbon IRDP and particle energy spectra in water are calculated from a set of basic beam data measured and submitted to RSL in order to generate the clinical beam model. The large angle component of the lateral scattering and of the nuclear fragments in inelastic nuclear reactions of a carbon ion beam is modelled in RS by a total of four Gaussian dose shape [1]. 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 was done step by step by increasing the complexity of the tests [2,3]. For all tests, the same experimental setup was reproduced in the TPS.

1D/2D commissioning

The IRDPs 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 16 energies selected over the clinical range. Comparison between calculations and measurements was done in terms of relative dose difference and physical range at 80% of the peak dose (R_{80}) [2]. In Figure 2 the setup with the PPIC and the MP3-PL is shown.

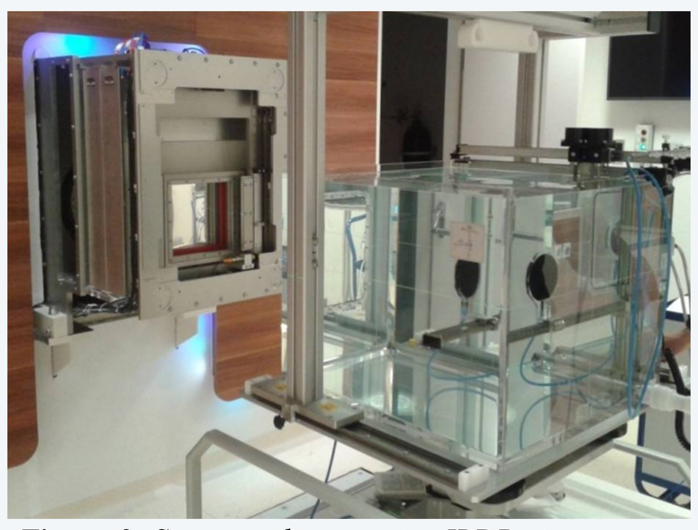

Figure 2. Setup used to acquire IRDPs in water at IR2HBL. The PPIC type 34070 was used as field detector in the MP3-PL water phantom.

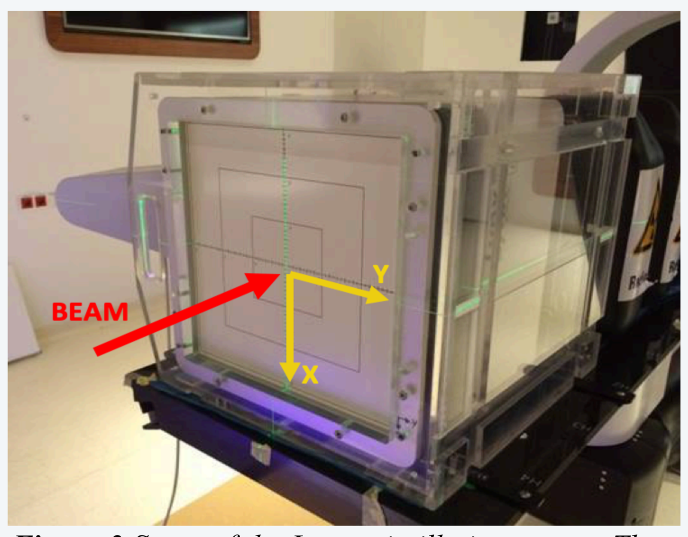

Figure 3 Setup of the Lynx scintillating screen. The x axis corresponds to the vertical plane of accelerator beam extraction and y axis to the horizontal plane.

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. For each energy measured FWHM were extracted by averaging FWHM from measured central axis x- and y-profiles of spot maps of 25 spots and compared to FWHM simulated by the TPS [2]. The measurements setup is shown in Figure 3.

Beam model calibration in terms of absorbed dose to water was carried out at the center of mono-energetic layers with the PTW-34001 Roos type chamber (model 34001, sensitive diameter 15.8 mm) positioned in water at the reference depths of 14 mm and at 75% of R_{80}. The relative deviations between the absorbed dose to water predicted by the TPS and the measured absorbed dose were evaluated [2,4].

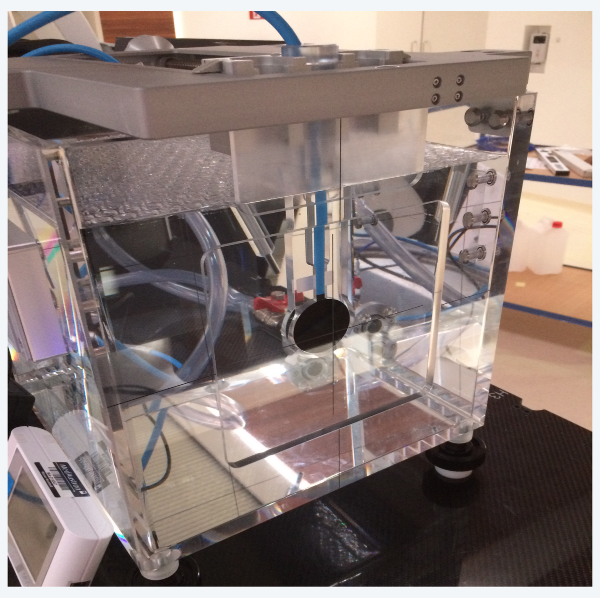

Figure 4 Setup of the Roos ionization chamber in the stationary water phantom at IR2HBL.

3D commissioning

Figure 5 Setup of 24 PinPoint ICs fixed to the PTW 3D detector block holder in a MP3-P water phantom

3D test cases were designed with increasing complexity of the dose calculation: from the box-shaped fields in homogeneous phantoms, over different complex target shapes, to more complex clinical cases. 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% [2,3].

Results

1D/2D commissioning

Relative dose difference between TPS calculated and measured IRDPs at ISD0cm showed an agreement within 1% and within 5% at ISD50cm with RaShi. The computed and measured R_{80} were in very good agreement within ± 0.1 mm at ISD0cm, see Figure 6.

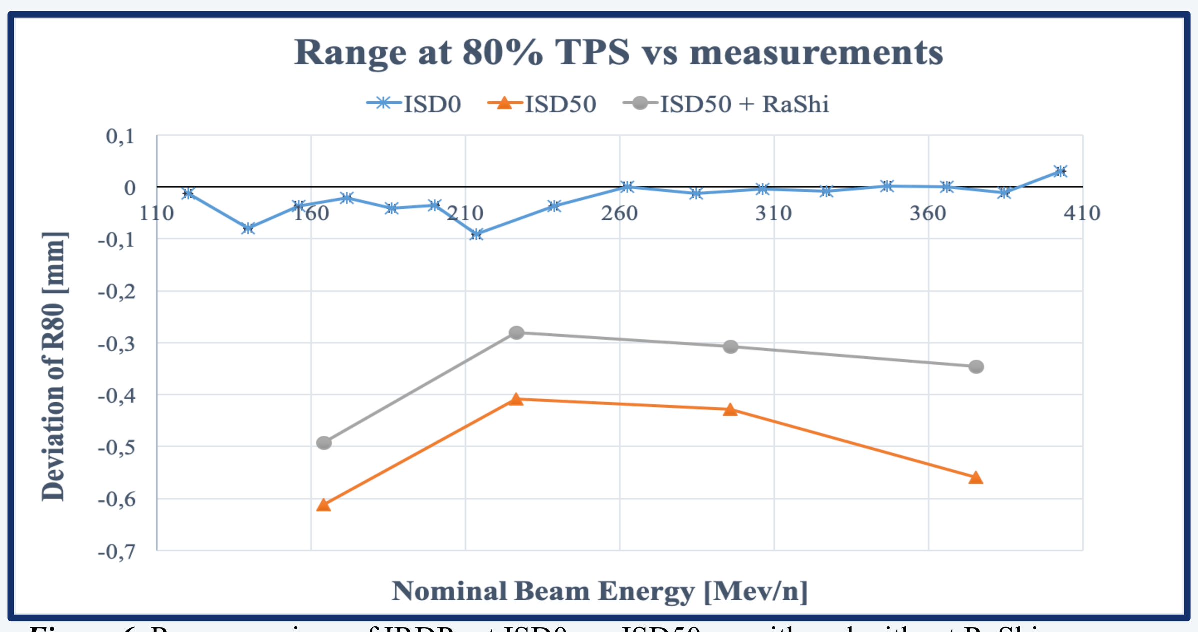

Figure 6. R_{80} comparison of IRDPs at ISD0cm, ISD50cm with and without RaShi.

For lateral spot profiles in air the average FWHM was within ±0.2 mm of the measured one at ISD0, ±0.3 mm at ISD40, ±0.3 mm at ISD50 and ±0.3 mm at ISD58 as shown in Figure 7.

Larger deviations were found at a reduced air gap, closer to the nozzle (ISD50 and ISD58). Indeed, here, the measured spot size is smaller and the FWHM in x and y are less symmetrical than those at ISD0cm (64.8 cm air gap) where the beam focusing is optimized and the asymmetry is compensated by the scattering in air. This asymmetry for non-isocentric setup cannot be reproduced by the TPS beam model which assumes a symmetric spot in x and y.

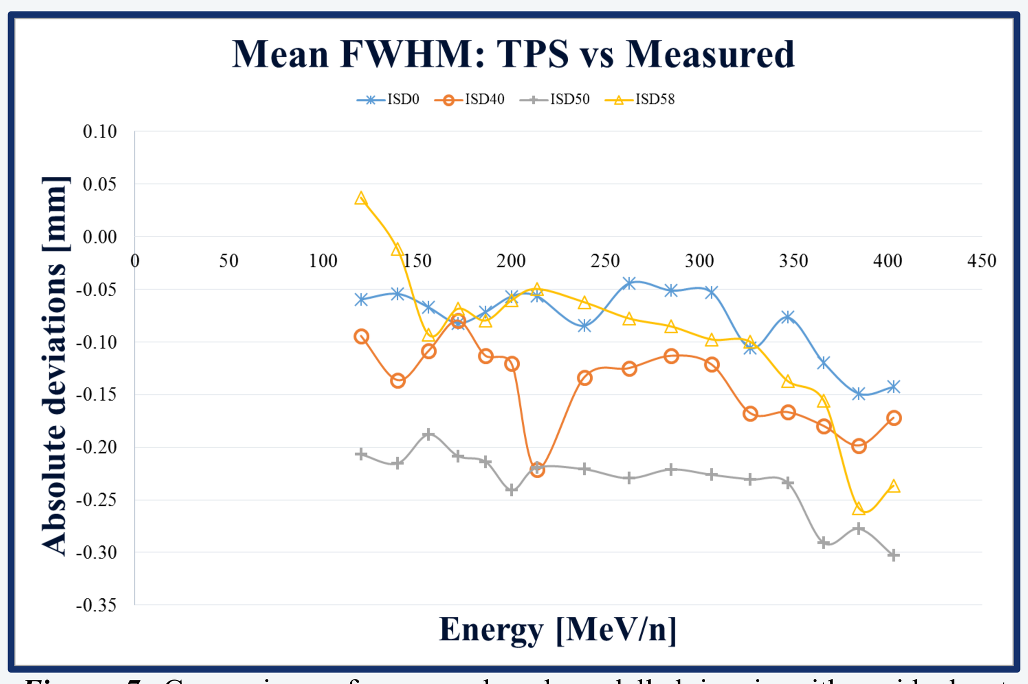

Figure 7. Comparison of measured and modelled in air with residuals at ISD0cm, ISD40cm ISD50cm and ISD58cm without RaShi.

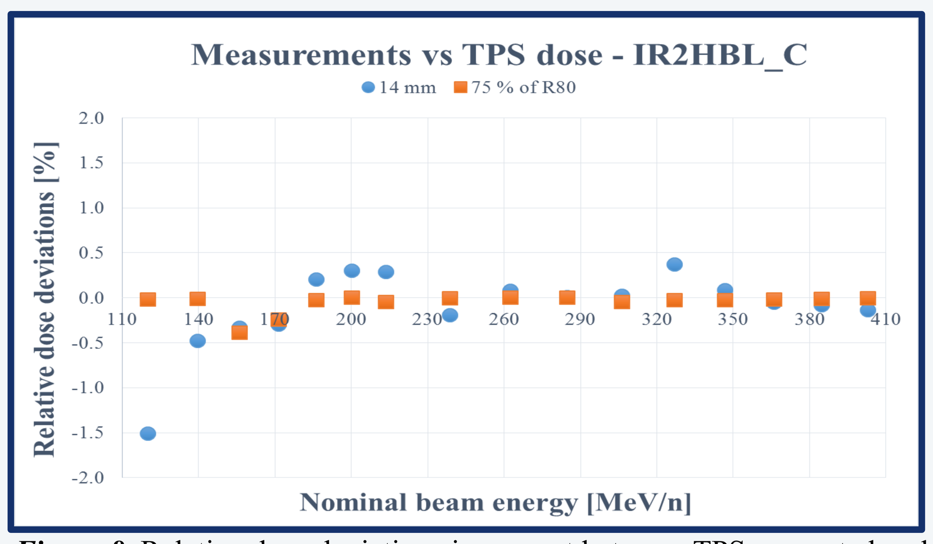

Figure 8. Relative dose deviations in percent between TPS computed and measured dose at the reference depths of 14 mm and at 75% of R_{80}.

In Figure 8 measured and computed relative dose deviations in water as function of the energy are reported. Excluding the 120 MeV/n all deviations are within ±0.5%. The largest deviation was observed for the 14 mm in water at 120 MeV/n which is mainly related to the measurement uncertainty of the high gradient dose region along the depth dose profile in water at that energy.

3D commissioning

The 3D commissioning for simple boxes in water at ISD0 showed a mean local dose difference within ±2% for shallow boxes in the target region (see Figure 9). Similar behavior has been observed at ISD50cm. Regarding the naming scheme of the plans the 1st number gives the side length of the cubic box and the other numbers the position of the box center lateral and in depth.

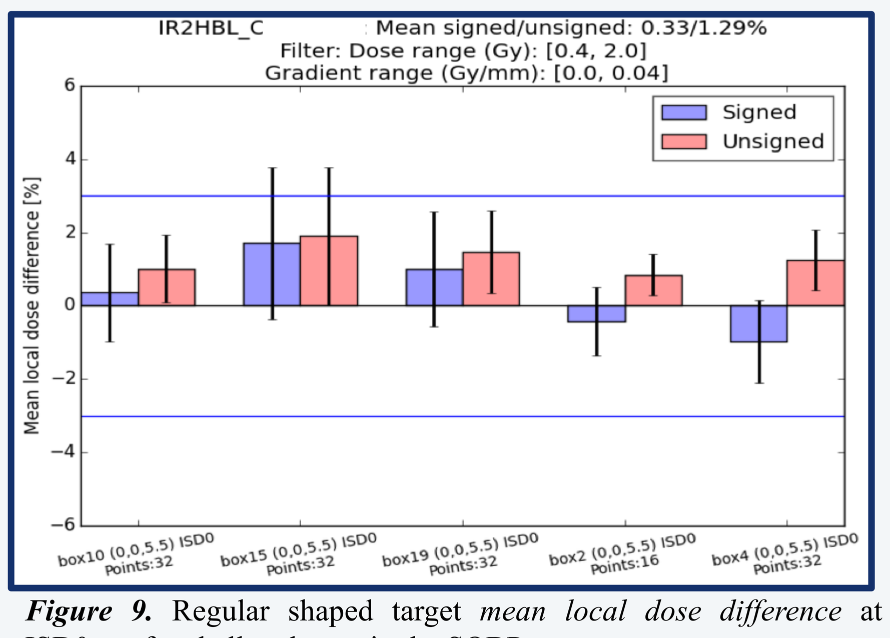

Figure 9. Regular shaped target *mean local dose difference* at ISD0cm, for shallow boxes in the SOBP.

For box-like targets in presence of RaShi the mean global deviations are within ±1.5% (see Figure 10).

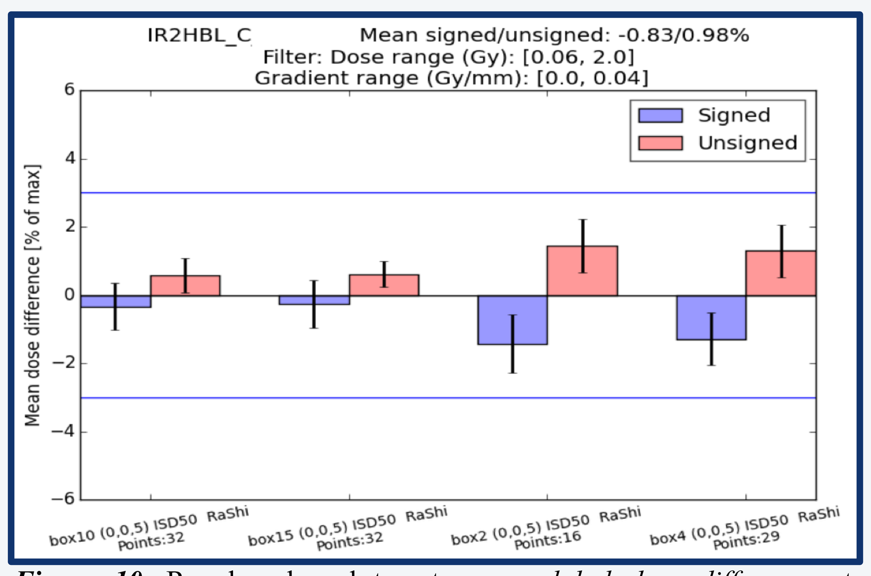

Figure 10. Regular shaped target *mean global dose difference* at ISD50cm with RaShi.

For the *head & neck sarcoma* case, no beams with range shifter were used. The mean global dose deviations were within ±2% for all the beams, as shown in Figure 11. Since the *mucosal melanoma* target volume was superficial, the RaShi was used and also here very good agreement, within ±1.2%, with the measurements was found for all beams.

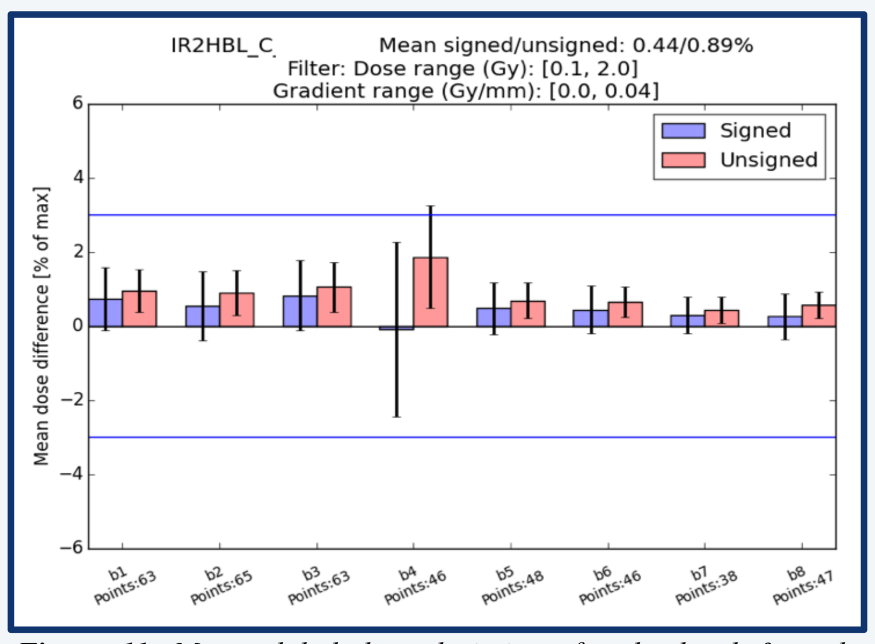

Figure 11. *Mean global dose deviations for the head & neck sarcoma case.*

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.

References:

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2. A. Carlino, T. Boehlen, S. Vatnitsky, L. Grevillot, J. Osorio, R. Dreindl, H. Palmans, M. Stock, and G. Kragl, "Commissioning of pencil beam and monte carlo dose engines for non-isocentric treatments in scanned proton beam therapy," Physics in Medicine Biology, 2019.
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