

Isocenter deviation assessment and model for Halcyon Radiotherapy Systems

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Abstract The radiation isocenter position on a Halcyon radiotherapy system was measured and the deviation from the intersection of the rotation axes, the ideal isocenter, implemented in Monte Carlo (MC) model. With a test VMAT plan, the isocenter deviation was assessed by analyzing the difference between the film measurement and MC simulated dose distribution. The implementation of the deviation improved the agreement between the MC model and the measured dose distribution especially in the steep dose gradient regions. While the treatment system delivery met all isocenter related specifications, the improvements demonstrated by the modeling of the isocenter displacements could lead to more accurate dose predictions for treatments where steep dose gradients are needed around small targets.

1 Introduction

The isocenter is the primary reference location of external radiotherapy beam. In ideal conditions, the mechanical isocenter of linear accelerator is defined as the point of intersection of gantry, collimator, and treatment table rotation axes. However, the gravity pull on the beam centerline and the mechanical uncertainties of the gantry cause systematic deviations of the isocenter position as a function of the gantry angle^{1,2}. The geometric position of the radiation isocenter during rotation is usually assumed to be inside a virtual spherical volume. The AAPM Task Group Report 142 (2009) recommends that up to ± 1 mm deviation is acceptable for stereotactic treatments³. Discrepancies in the isocenter position may lead to loss of target coverage or increased dose delivery to the healthy tissues as the exact position of the target is relative to the mechanical isocenter, and by considering the isocenter movement, the accuracy of stereotactic treatments could be improved¹.

The goal of this study was to measure the radiation isocenter position on a Halcyon radiotherapy system (Varian Medical Systems, a Siemens Healthineers Company). The results also represent Ethos Radiotherapy Systems as the platform shares the same beam generation and collimation components⁴. The deviation of the isocenter position was replicated with Monte Carlo (MC) model. On one hand, the MC model can act as a computational copy of an actual machine and provide a reference without uncertainties due to the mechanical variations, and on the other hand, it can inherit the known mechanical variations and mimic the behavior of the actual machine.

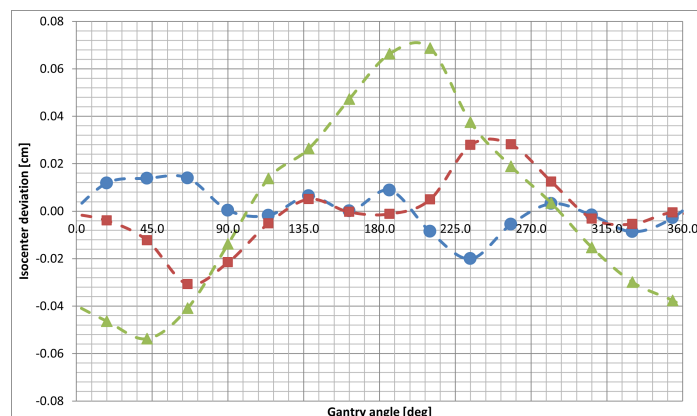


Figure 1: The radiation isocenter deviation of a Halcyon treatment unit (S4, Cancer Center, Helsinki, Finland) as a function of a gantry angle in IEC61217 coordinate system. The variations along the X-axis (blue dots), Y-axis (green triangle) and Z-axis (red square) are shown.

2 Materials and Methods

The deviation of the isocenter position on the Halcyon radiotherapy system ("S4") installed in the Helsinki Cancer Center was measured. Lateral (= XIEC61217) and vertical (= ZIEC61217) variation was determined using a star-shot procedure with fifteen equally spaced gantry angles¹. For the longitudinal (= YIEC61217) variation, a special film measurements procedure was designed. The projections of the star-shot beams were measured on XY- and YZ-planes with beam projections from the reference angles. Then, the alignment of the beams was compared to the alignment of the reference geometry and the offset was determined. The measurements were repeated to reduce the random uncertainty. The measured isocenter deviation data was implemented to the MC model by adjusting the source position and treatment head rotation accordingly. Each direction was interpolated and processed separately. The MC model has been validated to match to the vendor provided pre-configured beam model⁵. The machine-specific mechanical leaf gap (MLG) of -0.65 mm in nominal positions was used for both proximal and distal MLC stacks.

To analyze the impact and quantify the agreement between the machine delivery and predicted dose distributions, a test Volumetric Modulated Arc Therapy (VMAT) plan was produced. The test VMAT plan, from a manuscript under review⁶, had two optimized VMAT arcs (Photon Optimizer

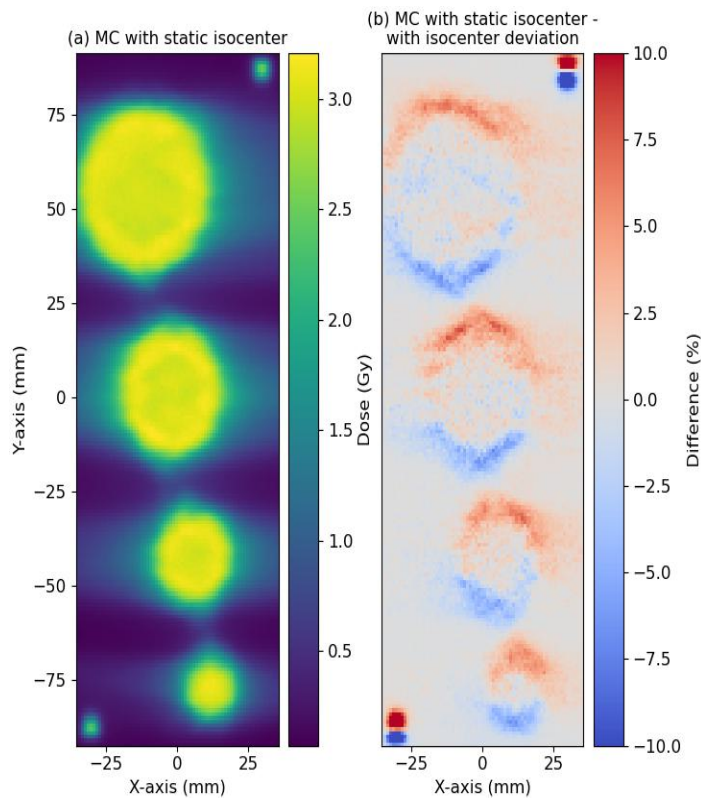


Figure 2: The MC simulated dose plane with static isocenter on the left and the relative dose plane difference between MC simulated dose planes with static isocenter and with isocenter deviation. Both graphs share the same Y-axis.

18.0.0⁷) with the collimator angles 30° and 330°, and one static alignment field with zero-degree gantry, which was used for confirm the film position. The plan had four spherical targets with the diameters of (4.0, 3.0, 2.0, 1.0) cm and the static alignment field had square 5 mm x 5 mm openings. The measured dose distributions were obtained by using GafChromic™ EBT3 radiochromic film (Ashland Speciality Ingredients G.P., Bridgewater, NJ), the Vidar DosimetryPro Advantage (red) densitometer (Vidar Systems Corporation, Herndon, VA), and the RW3 water-equivalent plastic phantom (PTW, Freiburg, Germany). The phantom size was 30 cm x 30 cm x 10 cm and source to surface distance (SSD) was 95 cm. The machine type had fixed 800 MU/min dose rate.

3 Results

The minimum distance between the center of the beam and the ideal treatment isocenter on a Halcyon radiotherapy system was measured with different gantry rotations. Figure 1 shows the isocenter deviation for each direction in IEC61217 coordinate system (X, Y, Z) as a function of a gantry angle. The range of the variation along X-direction was ± 0.02 cm (blue dots), ± 0.07 cm in Y-direction (green triangles), and ± 0.04 cm in Z-direction (red squares). The largest value of 0.069 cm was measured along Y-direction at 210°. The uncertainty in determining the isocenter deviation in each

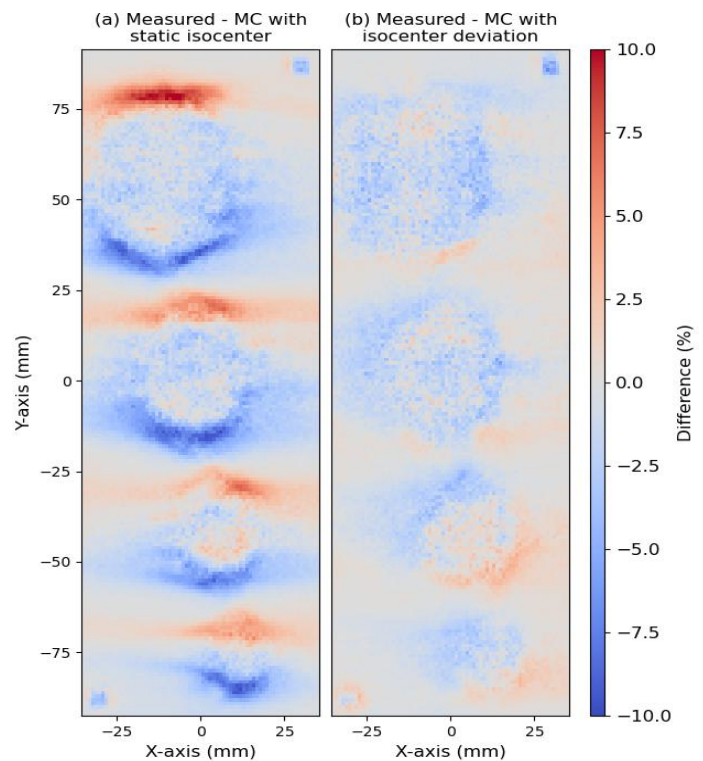


Figure 3: The relative dose plane difference between the measured and MC with static isocenter on the left and with isocenter deviation on the right. Both graphs share the same Y-axis.

direction separately was found to be ≤ 0.01 cm and the gantry angle uncertainty was $\pm 0.15^\circ$.

The measured isocenter deviation was implemented in the MC model and the results in comparison to static isocenter analyzed. For a test VMAT plan with the two fields and the collimator angles of 30° and 330°, the MC simulated dose plane is presented in Figure 2 (a). The dose plane has the four sphere targets, and on the two corners, 5 mm x 5 mm openings from the alignment field with zero-degree gantry. The relative dose difference between MC simulated dose with static isocenter and with isocenter deviation is shown in Figure 2 (b). The most profound differences are shown with the alignment field openings. With the VMAT fields, the effect is smaller, but shift-like differences up to 8 % are observed on the Y-edges of the targets.

The differences between the measured and MC dose planes are shown in Figure 3. The dose plane difference between the measured and MC with static isocenter is presented in Figure 3 (a). A systematic difference is observed on the Y-edges of the sphere targets similar to Figure 2. The largest dose differences reach up to 10 %. The positioning is correct as the alignment fields openings show no systematic differences. An improved agreement can be observed between the measured and MC with the implementation of the isocenter deviation in Figure 3 (b). Systematic differences are no longer present and the maximum difference is below 4.1%. By taking profiles passing through the spherical targets, the same

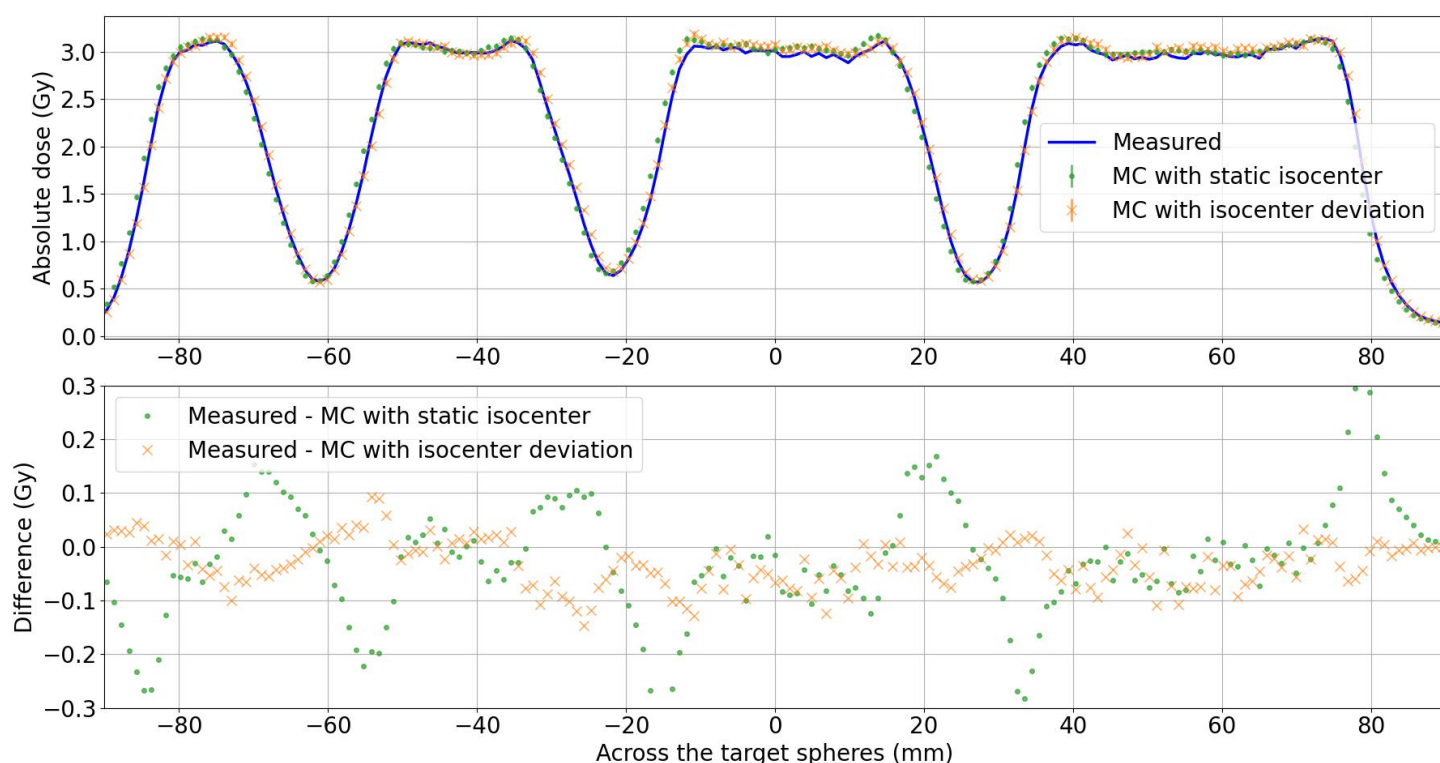


Figure 4: The dose profiles across the target spheres and the dose difference between the measured and MC.

observations can be confirmed in Figure 4. The dose profiles of the measured (blue line), MC with static isocenter (green dots), and MC with isocenter deviation (orange crosses) are presented on the top of the graph and beneath the local dose difference between the measured and MC dose profiles. The systematic shift between the measured and MC with static isocenter creates local deviations up to ± 0.3 Gy in the dose gradient regions. Between the measured and MC with isocenter deviation, the difference is smaller and the local deviations are only up to ± 0.15 Gy.

4 Discussion

The radiation isocenter deviation as a function of a gantry rotation was measured in all three dimensions on a Halcyon radiotherapy system. The deviation was less than 0.1 cm. The largest range of offset was observed with the longitudinal Y-axis up to ± 0.07 cm. The vertical Z-axis range was less than 0.04 cm and the lateral X-axis range was less than 0.02 cm. However, all directions are coupled by the collimator and the gantry angle. The effect of the isocenter deviation on the VMAT test plan was analyzed by taking into account the difference between the center of the beam and the ideal treatment isocenter in the MC model as a function of the gantry rotation. This study quantified the radiation isocenter deviation and its impact on the delivered dose for a test VMAT plan with spherical targets and high dose gradients. Although, the coincidence of the radiation beam to the mechanical axis was well below 1 mm, the effect can be modeled, leading to improved accuracy in the predicted dose

delivery. As the focus of this study was on the isocenter, the uncertainties from the MLC position and the gravity effect on the position during the gantry rotation was ignored. It should be kept in mind that with a clinical case, target delineation, patient setup error, and target movement would be larger sources of uncertainties.

5 Conclusion

Based on the measured data, a gantry angle-specific isocenter deviation was applied to a Monte Carlo model validated for the Halcyon and Ethos radiotherapy systems. The consideration of the isocenter variation with the gantry angle improved the agreement between the measured and simulated dose in the gradient regions of the test VMAT plan. Further considerations such as the impact on clinical plan quality of more sophisticated radiation isocenter modeling will be addressed in future studies.

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