# Comprehensive quality assurance and optimization of the clinical stereotactic environment in a practical setting: A study in collaboration with Massachusetts General Hospital


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## INTRODUCTION

As a clinical medical physicist, executing proper QA techniques is crucial to high quality treatment and care for patients. Almost as important as the procedure itself is being able to analyze the results that you achieve in order to keep an eye on any potential alarming trends or risks. Among many other QA routines, RIT has developed a comprehensive isocenter optimization module for a full diagnosis of the stereotactic environment, and RIT*trend*™ for logging results and further statistical processing. In practice, Massachusetts General/North Shore Hospital has been utilizing these tools for over 6 years for the purposes of recognizing abnormalities and correcting them when necessary.

## BACKGROUND

When evaluating a linear accelerator for SRS/SBRT treatment, the typical procedure for ensuring accuracy and precision is to execute a 'Winston-Lutz' test. Using a ball bearing at the mechanical isocenter, this test, described in *Low et. al. (1995)*, produces the Euclidean distance of the deviations in the X, Y, and Z directions, that result in a "weighted average" 3D displacement ($D$) from the current location in space [1].

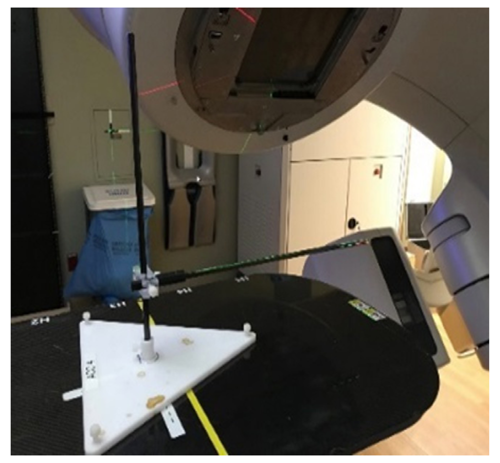
Theoretically, this standard definition fails to address some vitally important aspects of analyzing the stereotactic isocenter for radiation treatment:

- There is no delineation between contributions from gantry rotation and table rotation.
- The method does not account for collimator rotation.
- There is no definition of the size of the individual deviations at various gantry, table (and collimator) angles between the radiation field and the BB.
- Using the standard method, individual deviations of large magnitudes can combine into an overall displacement offset of 0, if the deviations are in opposite directions for opposing angles.
- There is no prescription provided to clinical physicist for how they can practically minimize the individual deviations.

To more precisely account for these factors, the RIT Isocenter Optimization routine was developed [2,3]. This method, as outlined in the RIT Isocenter Optimization Manual, provides a recommended angle configuration for 12-16 images that would accomplish a comprehensive overview of the stereotactic environment. Following the acquisition of these images in DICOM or HIS format, they are uploaded into the software for analysis.

This is an alternative solution to the Winston-Lutz test, where the goal is to understand the bounds of these results. This routine analyzes the image set to find the 3D maximum measured deviation ($W$) in the angle configurations utilized. Often the Winston-Lutz algorithm can result in a very low number, which can be misleading to the physicist or therapist when the actual largest deviations are much greater. In turn, if we follow the 1-mm mark for deviation for stereotactic treatment, as dictated by the AAPM TG-142 report, then it stands to follow that the configurations used to treat the patient would also fall under that guideline.

## METHODS



As part of the Varian TrueBeam SRS/SBRT pre-treatment QA procedures, the medical physicist places a Winston-Lutz pointer phantom on the table. The tip of the pointer contains a 5 mm tungsten carbide sphere and is positioned at mechanical isocenter as defined by the localization lasers. The phantom is weighted to prevent shifts during table rotation. A DICOM file containing the treatment beams is opened in File Mode. The field size of each field is 2.2 x 2.2 cm$^2$ with the MLCs defining a 2x2 cm$^2$ aperture.

**Image 1:** Set up of Winston-Lutz phantom at Massachusetts General/North Shore Hospital.

Twelve field geometries are used:

| Image | Gantry Angle | Table Angle | Collimator Angle |
|---|---|---|---|
| 1 | 0° | 0° | 90° |
| 2 | 0° | 0° | 270° |
| 3 | 90° | 0° | 90° |
| 4 | 90° | 0° | 270° |
| 5 | 180° | 0° | 90° |
| 6 | 180° | 0° | 270° |
| 7 | 270° | 0° | 90° |
| 8 | 270° | 0° | 270° |
| 9 | 0° | 45° | 90° |
| 10 | 0° | 90° | 90° |
| 11 | 0° | 270° | 90° |
| 12 | 0° | 315° | 90° |

MV images are added to each field automatically by restoring the previous imaging session. In this case, the EPID is positioned at 150 cm.

The physicist takes 12 fields without entering the room. The delivery takes less than 10 minutes. The images are automatically saved to a server that is linked to the TrueBeam Drive. The folder is date and time stamped. The DICOM tags in the image files are used to identify the gantry, table, and collimator angles of the fields. The images are analyzed using the Isocenter Optimization (3D) module in RIT v6.7. The coordinate system used is Varian IEC 1217 Reverse table.

The analysis presented in this work primarily utilized the 3D deviations derived from the Winston-Lutz test. The Winston-Lutz 3D Displacement ($D$) is a common QA metric that seeks to quantify the Euclidean distance of the mean deviations along the X-, Y-, and Z-axes, referred to as $DX$, $DY$, and $DZ$ [1,3]. An alternative metric to report is the maximum deviation across all angle configurations. In the RIT software, this is referred to as the "Maximum Measured 3D Deviation" ($W$) [2,3]. This study aimed to investigate the role these metrics play in monitoring QA status for two Varian TrueBeam LINACs (identified in this work as ACC2 and ACC4) over time. Data for ACC2 was collected over a period spanning June 2019 to March 2021 (N = 244). Data for ACC4 encompasses a period from June 2019 to March 2021 (N = 90).

Difference values were determined by: $Difference = W - D$

Among the resulting differences, a threshold of 1 standard deviation from their mean was utilized to classify points as 'outliers' (***Figures 2*** and ***4***). The classified outliers resulted in 19 instances for ACC2 and 6 instances from ACC4, which were isolated and used for further investigation. The raw differences of the outliers were plotted along with their mean (dashed, $\overline{D_O}, \overline{W_O}$) and, for reference, the total mean (solid, $\overline{D_T}, \overline{W_T}$) of all differences (***Figures 5*** and ***6***). In these plots, $W$ is represented in blue, while those of the corresponding $D$ is in orange.

## RESULTS

The results from this study provided a robust opportunity to analyze and test the theory behind the RIT Isocenter Optimization routine. The $D$ and $W$ values for Massachusetts General/ North Shore Hospital LINACs ACC2 and ACC4 were plotted against each other as seen in ***Figures 1*** and ***3***, respectively. Generally, the two results from each plot follow along the same pattern and trend.

In both LINACs, the mean of the differences between $D$ and $W$ was 0.2 mm (***Figures 2*** and ***4***). The standard deviation of those differences was 0.2 mm. A 1-standard deviation threshold (0.4 mm) of the differences served as the threshold point for segregating outliers. Across LINAC ACC2's data, a total of 19 outlier peaks were found, and for LINAC ACC4, a total of 6 outliers, as shown in ***Figures 5*** and ***6***, respectively.

The mean of all 3D displacement values for ACC2 ($\overline{D}_{T,2}$) was 0.31 mm (S.D. 0.15 mm), while the mean of all 3D maximum measured deviations ($\overline{W}_{T,2}$) was 0.52 mm (S.D. 0.20 mm). Among the outliers of ACC2, the mean 3D displacement ($\overline{D}_{O,2}$) was 0.14 mm - a negative 0.17-mm shift from the mean of all points (annotated as "Negative Delta Mean for 3D Disp." in ***Figure 5***). Conversely, a juxtaposed shift was observed in the opposite direction for the outliers of the 3D maximum measured ($\overline{W}_{O,2}$). The mean of those outliers was 0.52 mm, which represents a positive 0.36-mm shift from the total mean (annotated as "Positive Delta Mean for 3D Max." in ***Figure 5***). The absolute sum of the differences was 0.53 mm.

For ACC4, $\overline{D}_{T,4}$ was 0.46 mm (S.D. 0.21 mm), while $\overline{W}_{T,4}$ was 0.67 mm (S.D. 0.18 mm). The $\overline{D}_{O,4}$ of the identified outliers was 0.07 mm, which was a 0.40-mm decrease from 0.47 mm (annotated as "Negative Delta Mean for 3D Disp." in ***Figure 6***). Similar to ACC2, a positive shift of 0.21 mm was observed for $\overline{W}_{O,4}$, which increased to 0.88 mm (annotated as "Positive Delta Mean for 3D Max." in ***Figure 6***). The absolute sum of the delta means was 0.61 mm.

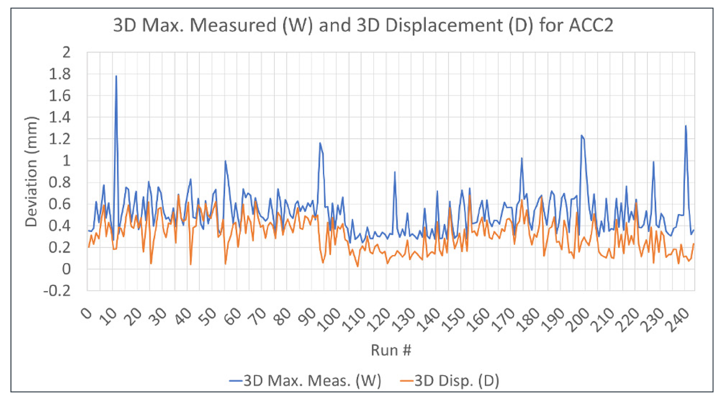



**Figure 1:** All 3D maximum measured ($W$) and 3D displacement ($D$) deviations for ACC2.

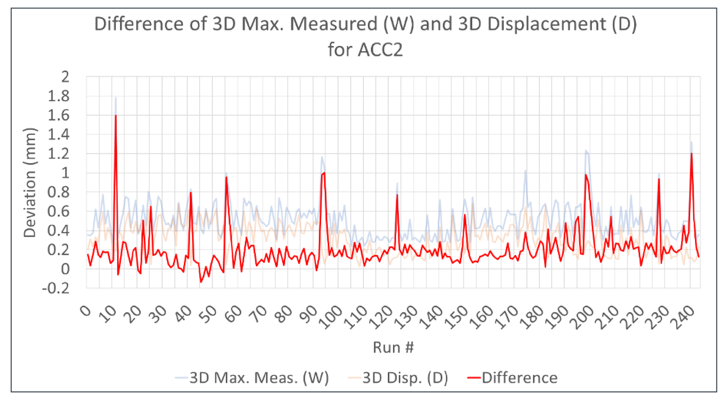



**Figure 2:** Difference plot for the 3D displacement ($D$) deviations from the 3D maximum measured ($W$) for ACC2.

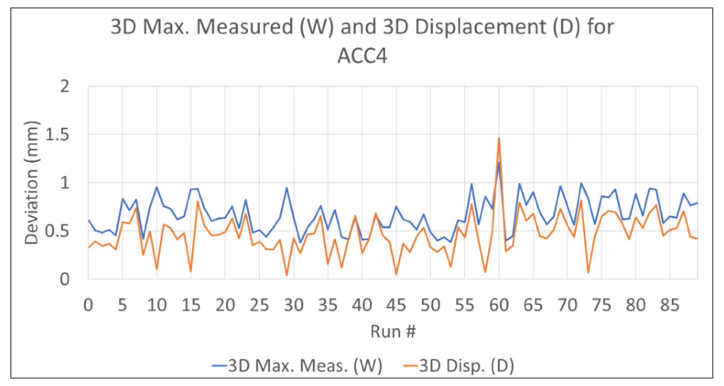



**Figure 3:** All 3D maximum measured ($W$) and 3D displacement ($D$) deviations for ACC4.

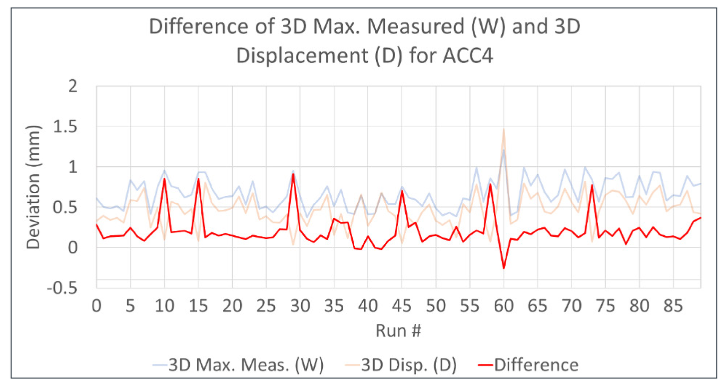



**Figure 4:** Difference plot for the 3D displacement ($D$) deviations from the 3D maximum measured ($W$) for ACC4.

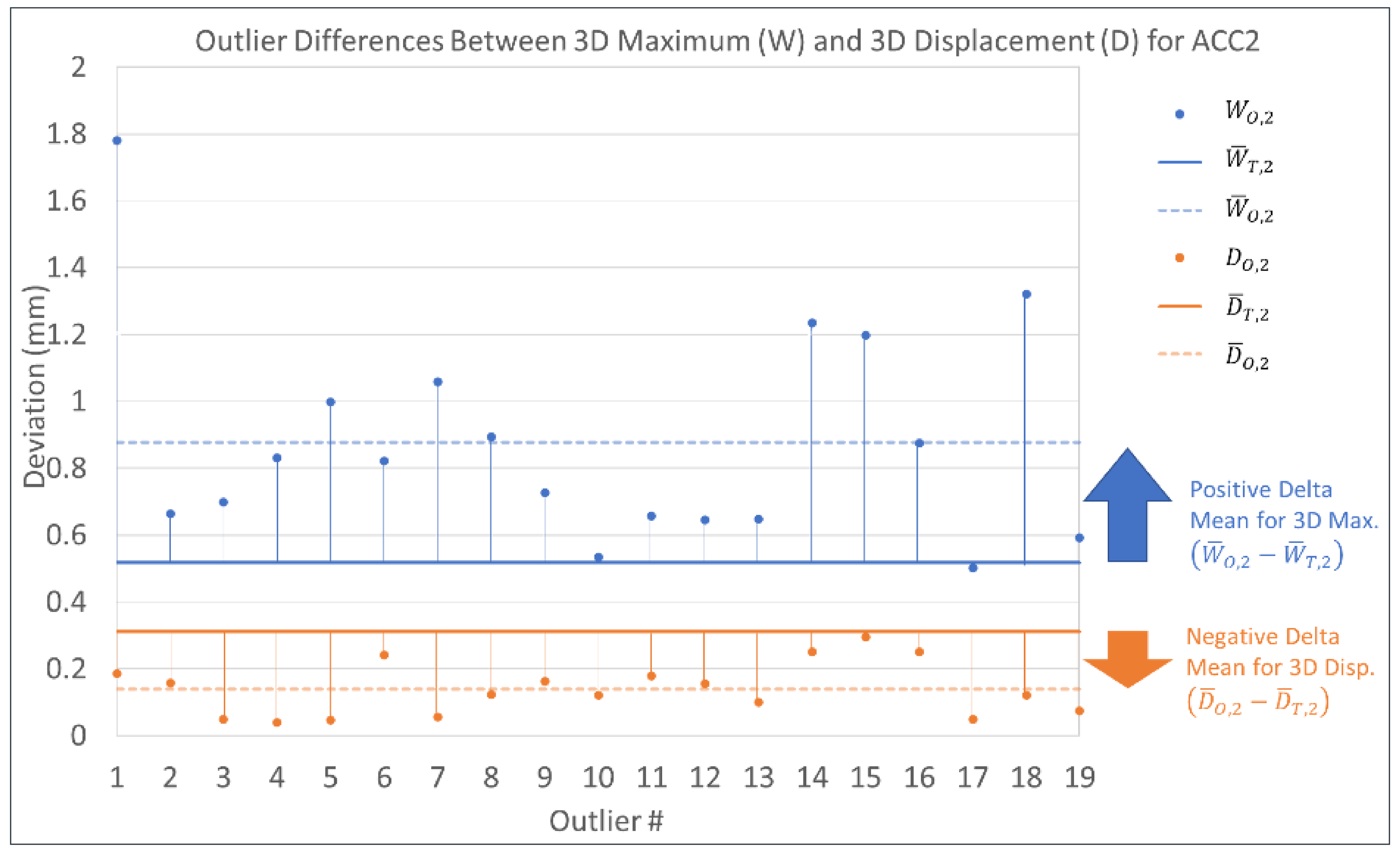



**Figure 5:** Opposing positive delta mean of the outliers experienced for the 3D maximum measured deviations ($W$, blue arrow) as compared to the negative delta mean of those same outlier points experience for in the calculated 3D displacements ($D$, orange arrow) for ACC2.

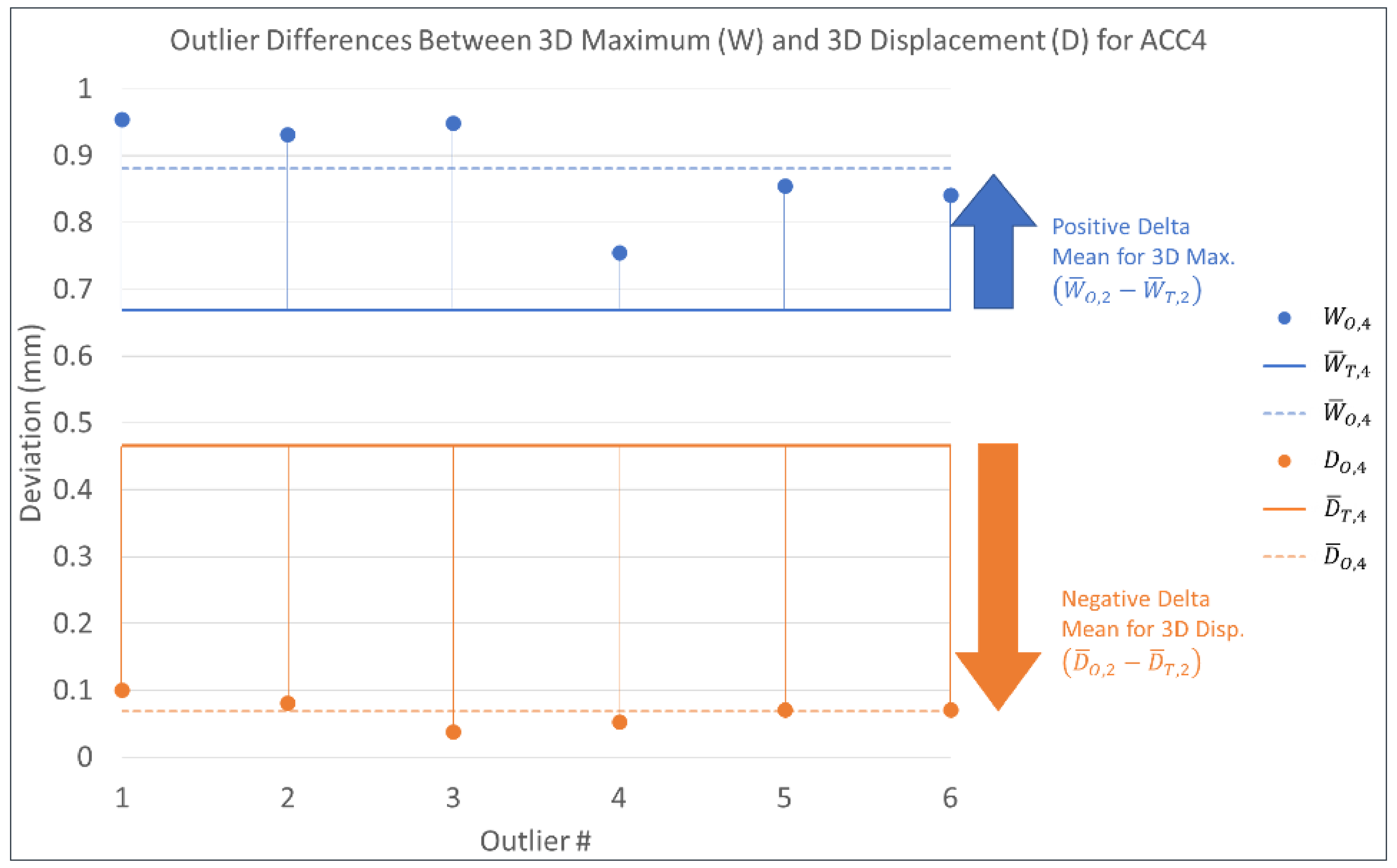



**Figure 6:** Opposing positive delta mean of the outliers experienced for the 3D maximum measured deviations ($W$, blue arrow) as compared to the negative delta mean of those same outlier points experience for in the calculated 3D displacements ($D$, orange arrow) for ACC4.

## DISCUSSION

The RIT Isocenter Optimization routine was developed in order to analyze these results and provide adjustments in order to optimize the stereotactic environment to the best level possible. A few assumptions were taken in this process:

- Gantry and table rotation accuracy are completely independent and can be treated as separate factors contributing to overall isocenter accuracy.
- Collimator rotation accuracy is dependent on gantry angle.
- For gantry rotation, the points of maximum deviation occur at the cardinal gantry angles.
- Collimator rotation accuracy can be completely characterized by 2 opposing angle images. In this case, 90° and 270° for the two Varian TrueBeams.
- There may be errors in image processing.

This method considers any large, offsetting deviations in the stereotactic environment that may not be necessarily obvious or recognized in the typical Winston-Lutz formulation. Occasionally, the 3D maximum measured deviation was larger than 1 standard deviation from the mean of its difference of the Winston-Lutz. There were 25 instances of this being the case across 334 data points from two different linear accelerators during a 21-month period.

Among the outliers for ACC2, the 3D maximum measured deviation mean increased by 0.36 mm, while the 3D displacement mean shifted by -0.17 mm. The 0.53 mm shift apart for these measurements was an unexpected finding of this study. The same can be said for ACC4, which saw a delta means diverge 0.61 mm apart. When viewed independently, the outlier data show that when the 3D displacement decreases significantly below its mean, there is, consequently, a significant increase of the 3D maximum measurement. This is in direct juxtaposition to the conclusions one may draw from lower-than-average 3D displacements resulting from a Winston-Lutz test, since they are likely to be accompanied by large offsetting individual deviations.

One reason for the observed phenomenon is due to the distribution of the deviations in the distance ($DX$, $DY$, $DZ$) calculations. It is noted that along the projected axes, if the deviations are distributed symmetrically around the 0-mm point, then the resulting distance metric will likewise be near 0 mm, regardless of the magnitude of the contributing individual deviations. The dilemma that this presents can be hypothetically illustrated by considering two maximum measured deviations +/- 2 mm from 0 mm, are, nonetheless, still averaged to be 0 mm, even though they are separated by 4 mm.

Run #60 of ACC4 provided one instance where the 3D displacement was significantly larger than the 3D maximum measured deviation. This could be explained by an issue with the collimator or significant wobble in the table. It is possible that after correcting ball set-up error and table axis shifts this error could be remedied.

## CONCLUSION

These specific instances of large outlier differences were found to occur randomly without any deterministic pattern or trend. This brings about the importance of regularly monitoring the 3D maximum measured deviation, so that it can be corrected and minimized when the outliers arise, potentially improving patient outcomes. We suggest that this is truly what it means to have submillimeter accuracy.

## CORRESPONDENCE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## REFERENCES


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[3] RIT (2019) Isocenter Optimization Manual. Radiological Imaging Technology, Inc., Colorado Springs, CO