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Three Years' Daily Off-Iso Winston-Lutz Test Experience

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Abstract

Background: Stereotactic radiosurgery (SRS) is one of the main approaches to managing brain metastases. Single iso multi-target (SIMT) treatment emerges as a new branch of SRS. Standard daily clinic quality assurance of SIMT is in the need to assure the treatment with high precision. **Purpose:** This study reports a three years' longitudinal experience of performing daily (the day of SRS/SBRT/SIMT treatment) Off-Isocenter Winston-Lutz (OWL) test on one VitalBeam linear accelerator (Varian Medical Systems, Palo Alto, CA). A practical workflow and detailed radiation-mechanical spatial discrepancy information associated with six ball bearings (BBs) inside MMWL phantom (Sun Nuclear, Melbourne, FL) are reported for the first time in routine clinical practice. **Method:** The daily Off-iso Winston-Lutz (OWL) test was performed on one VitalBeam Linac which is equipped with a 120-leaf Millennium Multileaf Collimator (MLC) and a standard IGRT couch. Imaging capabilities include onboard kV and MV system that supports both 2D radiographic and 3D CBCT acquisitions. The MultiMet phantom and QA software (v2.1) are from Sun Nuclear Inc. The "Excluding 45˚ Couch Kicks" 10-beam plan was adopted in Aria 16.1 R&V and Eclipse system (v16.1). The plan utilizes eight distinct Gantry-Couch-Collimator (GCC) angle configurations. An institutional workflow of off-iso Winston-Lutz test was established and implemented to ensure high-precision measurements with minimal impact on the daily treatment schedule. **Results:** The three years (May 2023-May 2026) OWL test were conducted on eight gantry, couch and collimator (GCC) angle sets. A total of 81 valid and formatted reports were collected and analyzed. Initial phantom positioning offset and final radiation-mechanical field center offset are reported. From GCC (0, 0, 0), GCC (0, 90, 0) and GCC (0, 0, 270) three years' trend, it clearly showed that the further the target is from iso center, the larger radiation-mechanical spatial discrepancy is. From the GCC (90, 0, 90), GCC (180, 0, 90) and GCC (270, 0, 90) three years' trend, it suggests us the gantry sagging as a contribution factor to affect the discrepancy in this VitalBeam linear accelerator. **Conclusions:** Three years of daily implementation off-iso Winston-Lutz test experience confirm that the OWL test is a feasible and highly valuable routine QA practice. The rich spatial discrepancy information provides actionable insights for the plan designer to optimize the beam placement and refine isocenter selection for complex targets. As continued technological advancement and workload optimization in phantom position and image analysis automation in the near future, the off-iso Winston-Lutz test shall become a standard QA practice for both single- and multi-target SRS/SBRT/SIMT programs.

Keywords

SRS/SBRT/SIMT, Off-Iso Winston-Lutz Test

1. Introduction

Brain metastases are primarily secondary malignancies which originate from the lung, breast, colon, kidney, and melanoma. Standard management strategies include surgical resection, radiotherapy, and systemic therapies, such as targeted therapy, immunotherapy, and antibody-drug conjugates (ADCs). Within radiotherapy, the primary approaches are Whole-Brain Radiotherapy (WBRT), Hippocampal-Avoidance WBRT (HA-WBRT), and Stereotactic Radiosurgery (SRS) [1]. Numerous clinical trials comparing these approaches—WBRT vs. SRS, WBRT vs. HA-WBRT, and HA-WBRT vs. SRS—have either been completed or are currently still ongoing [2].

WBRT and HA-WBRT are designed to prevent microscopic disease from progressing into radiographically visible macroscopic metastases. These techniques deliver a relatively low, uniform dose to the entire brain parenchyma. In contrast, SRS focuses on local control of visible macroscopic metastases, utilizing high, non-uniform, conformal doses to irradiate one or several lesions simultaneously. Because their clinical objectives differ, their outcomes vary significantly: WBRT and HA-WBRT achieve superior global intracranial control at the cost of increased neurocognitive decline, whereas SRS offers excellent local control but carries a higher risk of distant intracranial failure [1]. While HA-WBRT aims to mitigate cognitive deficits, its low-dose profile often fails to control visible metastases, frequently necessitating salvage re-treatment. Although Phase III trials comparing HA-WBRT and SRS are ongoing (expected completion in 2028) [2], the dosimetric superiority, organ-at-risk (OAR) sparing, and abbreviated treatment schedules of SRS still dominate the management of brain metastases for the foreseeable future.

Since Lars Leksell first proposed SRS for brain metastases in 1951 [3], the field has evolved over several decades—transitioning from early Gamma Knife systems to modern Linacs, CyberKnife, Tomotherapy, Proton therapy, and the ZAP-X platform. Furthermore, the application of stereotactic radiosurgery (SRS) has expanded from brain metastases and non-malignant (benign) intracranial tumors to extracranial sites via Stereotactic Body Radiotherapy (SBRT). In recent years, it progressed into the Single-Isocenter Multitarget (SIMT) SRS/SBRT era based on modern Linac popularity.

The emergence of SIMT has significantly benefited patients who cannot tolerate the prolonged treatment times associated with invasive frame-based Gamma Knife or frameless CyberKnife procedures. However, the standardization of SIMT prescriptions, PTV margins [4], planning optimization, and routine Quality Assurance (QA) remains a challenge. Currently, the medical physics community lacks a practical consensus guideline for SIMT routine QA. While the forthcoming AAPM TG-362 report is expected to provide much-needed guidance, there is an urgent need for rigorous clinical standards regarding the implementation and frequency of these routine QA tests.

To address these QA needs, the off-isocenter Winston-Lutz (OWL) test was developed. First proposed in 2016 by Gao and Liu, the OWL test evaluates the congruence between the radiation and mechanical field centers when treating off-isocenter targets during SIMT [5]. Over the past decade, various phantoms, software, and methodologies have been developed to perform this test across different Linac platforms [6]-[11]. In this publication, we present our very recent three-year data and experience of implementing the OWL test in daily clinical practice (specifically on days of SRS/SBRT/SIMT procedures). To the authors' knowledge, this represents the first reported routine clinical QA measurement and workflow for SIMT. The Multi-Met Winston-Lutz (MMWL) system (Sun Nuclear, Melbourne, FL) was utilized for its clinical efficiency and simplicity on a dedicated VitalBeam linear accelerator (Varian Medical Systems, Palo Alto, CA).

2. Materials and Methods

2.1. Linear Accelerator Configuration

Daily off-isocenter Winston-Lutz (OWL) testing was conducted over a three-year period (May 2023-May 2026) on a newly installed VitalBeam linear accelerator (Varian Medical Systems, Palo Alto, CA). The VitalBeam platform shares the same high-stability waveguide architecture as the TrueBeam system, offering equivalent accuracy and precision for cranial SRS and extracranial SBRT. The system incorporates fully digital control of all major mechanical components—including the gantry, collimators, and couch—facilitating automated calibration, initialization, and image acquisition.

The accelerator is equipped with a 120-leaf Millennium Multileaf Collimator (MLC) featuring a 5 mm central leaf width and a standard IGRT couch. Imaging capabilities include onboard kV and MV systems that support both 2D radiographic and 3D CBCT acquisitions for patient positioning and machine QA. In this study, the MV imager was utilized for portal dosimetry and OWL measurements. The system operates on version 2.7 software and was commissioned in

March 2023 with four photon energies (6X, 6FFF, 10X, 15X) and five electron energies (6 - 20 MeV). The clinical workflow is integrated through the ARIA Record & Verification (R & V) system and Eclipse 16.1 Treatment Planning System (TPS).

2.2. Phantom and Software Specifications

The OWL test was performed using the MultiMet-WL system (Sun Nuclear, Melbourne, FL). This cubic phantom contains six spherical tungsten carbide ball bearings (BBs) embedded within a uniform 19.5 × 8.5 × 8.5 cm^3 volume (**Figure 1**). Each BB measures 5.0 ± 0.025 mm in diameter, with a manufacturing tolerance for spatial placement of ±0.05 mm. Surface-engraved crosshairs indicate the central isocenter BB, while five additional BBs (labeled 1 - 5 in the analysis software) are positioned superiorly and inferiorly to assess off-isocenter accuracy.

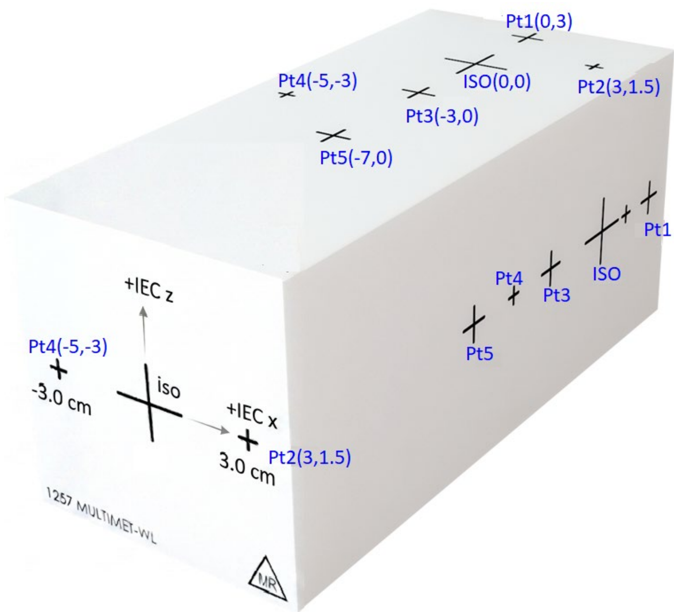

Figure 1. Schematic representation of the coordinate system of the SNC MultiMet-WL Cube phantom.

Image analysis was conducted using the MultiMet-WL QA 2.1 software, designed to analyze portal images from Varian or Elekta platforms. To minimize the clinical impact on a high-volume treatment machine, a streamlined "Excluding 45˚ Couch Kicks" 10-beam plan was employed in place of the "Including 45˚ Couch Kicks" 19-beam plan option. This 10-beam "step-and-shoot" plan utilizes cardinal gantry, couch, and collimator angles (**Figure 2**) to irradiate the six BBs using a 2 × 2 cm^2 field with 50 MU per beam. All positional coordinates were analyzed using the IEC 601-2-1 convention for both 3D (X, Y, Z) and 2D (V, U) reference frames. To simplify daily setup, the MMWL phantom was used as a standalone device without the StereoPhan cylindrical phantom. This is different from the configuration described by Poder *et al.* [12].

Treatment Delivery Angles		
Gantry	Couch	Collimator
0°	0°	0°
0°	0°	90°
0°	0°	270°
0°	90°	0°
0°	270°	0°
90°	0°	90°
180°	0°	90°
270°	0°	90°

Figure 2. Gantry-Couch-Collimator (GCC) configuration for the 10-beam, 8-angle delivery scheme.

2.3. Clinical Workflow and Implementation

Because no formal AAPM or regulatory guidelines currently exist for routine SIMT QA, an institutional policy was developed based on the MultiMet-WL User Guide and manufacturer-recommended safety protocols. Following initial software configuration and integration with the R & V system (including implementation of the "Excluding 45˚ Couch Kicks" plan), the physics team conducted extensive validation testing. Once performance and reproducibility were confirmed, the senior radiation therapists were trained first to independently perform the procedure as part of routine clinical operation. Later on other therapist catch up from the trained senior therapist.

The workflow emphasizes high-precision initial phantom positioning, requiring translational accuracy better than 0.5 mm, as well as couch and collimator rotational stability within 0.5˚. This approach provides a streamlined, yet robust alternative to more time-intensive multi-linac methodologies reported in previous studies [10]. Since the off-iso Winston-Lutz test inherently includes a standard Winston-Lutz test—already mandated by AAPM Task Groups TG-142 and TG-101 and by credentialing organizations for SRS and SBRT—our institutional policy extends this requirement by implementing the OWL test on a daily basis for every SRS/SBRT/SIMT procedure.

To ensure efficiency and minimal impact on patient daily treatment schedule, the daily clinical workflow is optimized as follows:

1) Alignment: The MultiMet-WL phantom is positioned on the treatment couch, and the isocenter BB is aligned to the room lasers using the engraved surface markers.

2) Verification: A 2D/2D MV-MV (or kV-kV) image match is performed to verify the alignment of the internal BBs with the BBs in the DRR image.

3) Delivery: The automated 10-beam "Excluding 45˚ Couch Kicks" QA plan is executed.

4) Analysis: Acquired portal images are exported to the MultiMet-WL QA software for automated analysis and report generation.

5) Review: A qualified physicist reviews the report to confirm that the mechanical-radiation field congruence meets clinical tolerances for SRS/SBRT/SIMT.

3. Results

The daily off-iso WL (OWL) tests were conducted over a three-year period from May 2023 to May 2026 right after finishing commissioning and starting SRS/SBRT/SIMT treatment in 2023. A total of 81 valid and formatted OWL reports were collected and analyzed. In current center, only one SRS/SBRT procedure is treated on every SRS/SBRT day. Each test report includes radiation-mechanical field center offset "Results Summary", "Couch Rotation Test", "Collimator Rotation Test" and initial "Positional Offset" results. Since in the daily test the "Couch Rotation Test" and "Collimator Rotation Test" are almost always ≤ 0.1˚ and much less than 0.5˚, they are not presented in this publication. The analysis therefore focuses only on initial position offset results and radiation-mechanical field center offset results.

It is the consensus that the initial position accuracy will directly affect the precision of final radiation-mechanical field center offset. **Figure 3** summarizes the cumulative initial setup uncertainties resulting from laser alignment and MV-MV (or kV-kV) image matching. The three couch rotational axis uncertainties (pitch, roll and yaw) naturally remain consistent within 0.2˚ since the standard IGRT couch has no pitch, roll and yaw correction. Three couch translational position uncertainties (lateral, longitudinal and vertical) are within 0.5 mm at a 95% confidence level. During the first year of clinical implementation (around the first 36 measurements), occasional excursions beyond the 0.5 mm tolerance were observed in the vertical and longitudinal directions. These deviations likely reflect a combination of early machine performance stabilizing and the learning curve associated with therapist training, as well as the workflow optimization. In contrast, data from the subsequent two years demonstrated excellent stability, with all initial positioning metrics consistently well controlled within the tolerance.

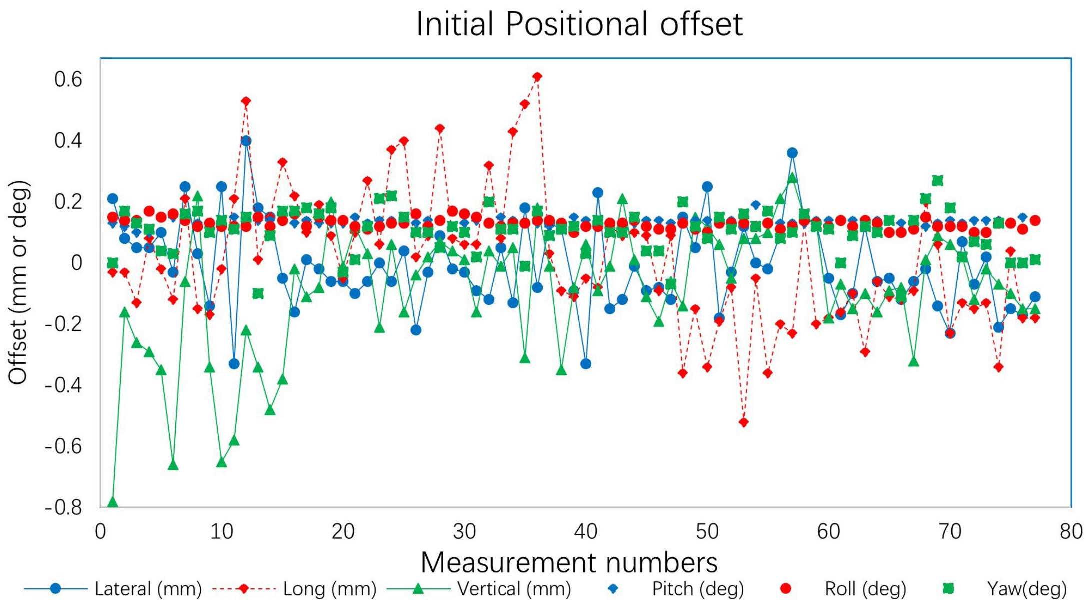

Figure 3. Initial positional offset measurements from three years of off-isocenter Winston-Lutz test reports.

The Radiation-Mechanical field center offsets are presented for each gantry, couch and collimator (GCC) configuration as shown in **Figure 4** individually. The trend of each target was plotted respectively in different color and line style. It enables the intuitive visualization of each target performance without complicated statistics analysis. This visualization proved particularly valuable for interdisciplinary communication among radiation oncologists, medical physicists, dosimetrists and therapists. It clearly illustrated the radiation-mechanical spatial discrepancy distribution in the 3-D radiation available space. It can provide practical strategy guidance of optimal arc beam placement and iso center selection supporting dosimetrists in designing high quality treatment plan. It further assists therapists in achieving reproducible accurate patient setup during the treatment. A 1mm tolerance line was also indicated by dash lines in each subplot.

The first three (No 1, No 2, No 3) plots of GCC (0, 0, 0), GCC (0, 90, 0) and GCC (0, 0, 270) showed that the Target 5 offset line is above all other target offset lines and it has the largest offset in the past three years overall. Occasionally the offset exceeded 1mm tolerance. Target 5 revealed the necessity of off-iso Winston-Lutz test in daily SRS/SBRT/SIMT practice because Target 5 is about 7 cm away from isocenter. These three plots hold the rule pretty good that the off-iso distance is larger, the offset between radiation field and mechanical field center is bigger. The iso center Target exhibited standard Winston-Lutz test performance with all, but two measurements in GCC (0, 0, 270), remaining within 1 mm tolerance which is acceptable in standard SRS/SBRT practice [13]. Targets 1, 2, 3 and 4 remained within the 1 mm tolerance for the vast majority of measurements.

The next two (No 4, No 5) plots of GCC (0, 0, 90) and GCC (0, 270, 0) demonstrated that all target offsets—including those at the largest off-isocenter distances—were consistently below the 1 mm tolerance. No target exhibited systematically superior or inferior performance. These angles therefore represent geometrically and radiologically robust beam orientations suitable for single-isocenter multi-target (SIMT) treatments, even when the target is as far as 7 cm away from the isocenter.

The last three (No 6, No 7, No 8) plots of GCC (90, 0, 90), GCC (180, 0, 90) and GCC (270, 0, 90), in contrast, clearly revealed consistently larger offsets for Target 1 relative to other targets across all three years. During first year its offset frequently exceeded 1mm tolerance particularly at No 7-GCC (180, 0, 90) where the Linac gantry rotates downward the floor. Target 5, despite being the farthest from the isocenter, shows an offset nearly equivalent to that of the isocenter. Because these beams share the same couch (0˚) and collimator angles (90˚), with varying gantry angles (90˚, 180˚ and 270˚), the observed behavior strongly suggests gantry sag as a contributing factor. Additionally, considering the initial position offset in the first year (approximately 36 measurements) shown in **Figure 3**, variations in operator proficiency may also have influenced the results. This will be further elaborated in the discussion section.

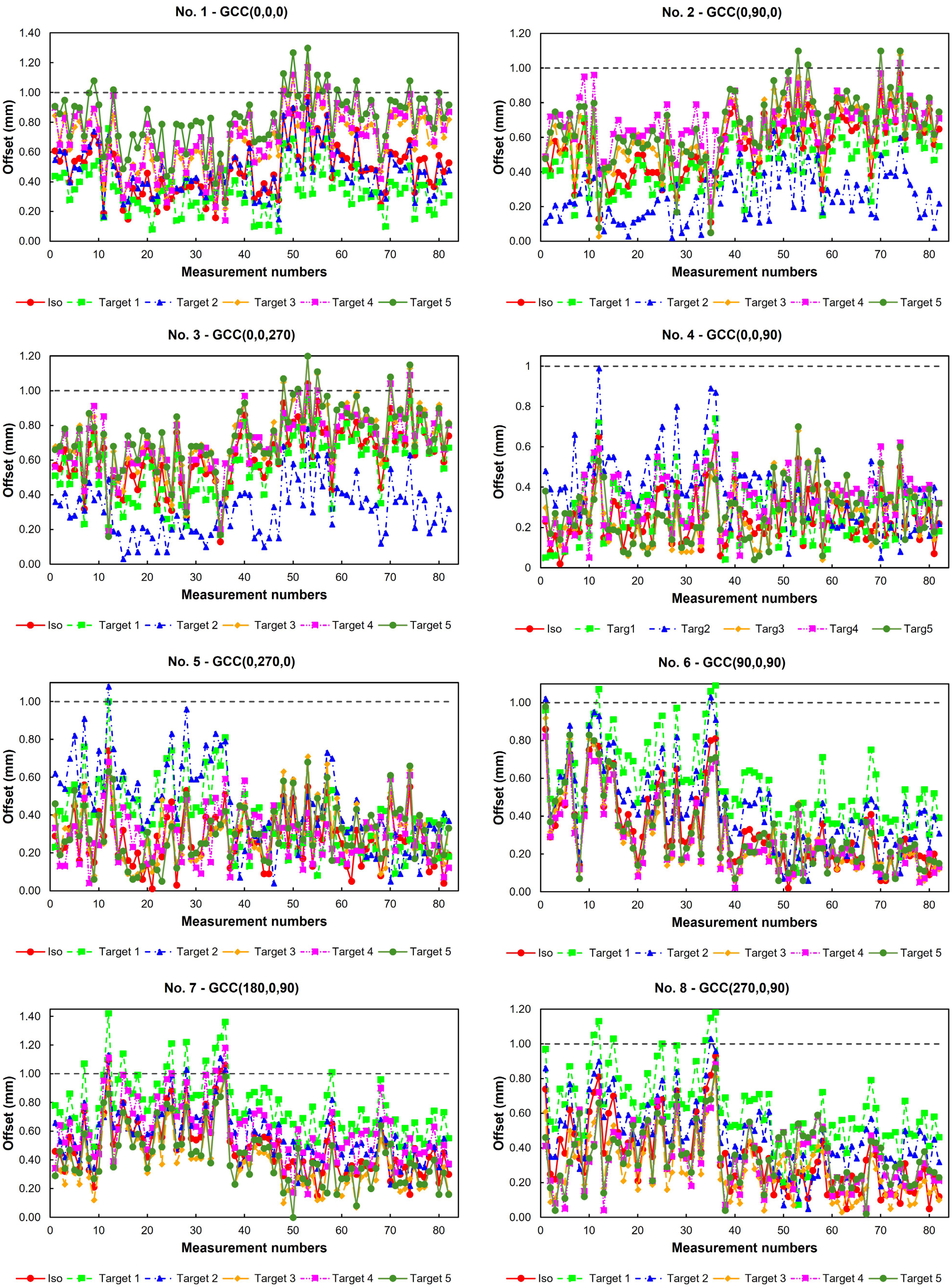

Figure 4. Radiation-mechanical field center congruence offsets for isocenter and off-isocenter targets across all gantry-couch-collimator configurations.

4. Discussion

To the authors' knowledge, this study is the first report of daily OWL testing integrated into the routine clinical SRS/SBRT/SIMT workflow. There is limited prior practical experience to draw upon. From our clinical perspective, any daily quality assurance (QA) procedures, equipment and methodology must be practical, reliable, stable, robust and as simple as possible. Importantly, it should not impose additional workload or disrupt the daily treatment schedule for the therapist.

After carefully evaluating several available off-isocenter Winston-Lutz test solutions, including the OneIso phantom [9], VisionRT Phantom, film-based methods, anthropomorphic phantom and SNC MMWL QA system etc., we selected the SNC MMWL QA system. This decision was driven not only by its commercial availability but also by its practicality, robustness, less man-made complexity, all of which align well with our clinical needs.

What is more, this system can quantify the initial phantom positioning accuracy. This capability is often ignored by physicists or therapists and is hard to report in other approaches, but yet directly affects the final measurement accuracy of each BB. In addition to the standard Winston-Lutz and off-iso Winston-Lutz test, the system enables monitoring of couch and collimator rotational accuracy, both of which remained within 0.5˚ over three years of QA data. The user-friendly report which is created by the MultiMet-WL QA 2.1 software is an additional operational advantage.

Because the OWL test inherently includes the standard WL test required by AAPM TG reports and credentialing bodies, its implementation facilitated departmental approval for daily testing on days involving SRS/SBRT/SIMT procedures. The consistently high-quality execution, particularly by our experienced senior therapists, played a critical role in achieving successful implementation and stable performance over the past three years.

Analysis of the first three beam configurations of No 1-GCC (0, 0, 0), No 2-GCC (0, 90, 0) and No 3-GCC (0, 0, 270), indicates that single-isocenter, single-target SRS/SBRT treatments can safely utilize these beam angles while maintaining submillimeter (<1 mm) accuracy. However, for single-isocenter multi-target (SIMT) treatments, planners should avoid putting targets at positions corresponding to Target 5 (approximately 7 cm from isocenter). For these beam configurations, treatment accuracy decreases as target distance from the isocenter increases.

In contrast, the beam configurations in the last three plots of No 6-GCC (90, 0, 90), No 7-GCC (180, 0, 90) and No 8-GCC (270, 0, 90) consistently show larger offsets for Target 1 compared to other Targets over the three-year period, while Target 5 exhibits offsets comparable to the isocenter target. The largest deviations occur at gantry angle 180˚ (head toward ground), suggesting a strong contribution from gantry sagging, which can reach 0.7 to 1 mm in the superior and inferior direction due to gravitational loading of the linac head and imaging components, previously quantitatively studied by Du *et al.* in 2012 [14].

Interestingly, the first 36 measurements (corresponding to first-year data) showed higher target offsets compared to subsequent years. Considering that the initial vertical and longitudinal positioning offsets were also larger during this period (**Figure 3**), the authors attribute this early variation to the clinical learning curve and subsequent refinement of setup techniques.

At the No 4-GCC (0, 0, 90) and No 5-GCC (0, 270, 0) angles, all targets remained within the 1mm tolerance. This suggests that beams going through these angles are highly reliable for any SRS/SBRT/SIMT target in the space within a 7 cm radius of the isocenter.

Overall, these three years of daily OWL data is far more informative than the standard Winston-Lutz test alone. While the standard Winston-Lutz test only illustrates the radiation-mechanical congruence at a single point (isocenter), the OWL test characterizes this agreement throughout the 3D space. This enables intuitive, consistent, and robust assessment of spatial accuracy across clinically relevant target positions. Our experience demonstrates the feasibility and clinical value of implementing daily OWL testing in Linac-based SRS/SBRT/SIMT programs.

Current limitations of the daily OWL workflow include increased workload and restriction to a 10-beam plan (Excluding 45˚ couch kicks). Automation of phantom setup, image acquisitions and analysis remains an important unmet need. Future development, similar to automated QA platforms such as TrueBeam MPC test or SunCheck Machine, could enable efficient implementation of more comprehensive beam sets, including a 19-beam plan (including 45˚ couch kicks), thereby providing enhanced characterization without adversely impacting clinical efficiency.

5. Conclusion

This three-year daily longitudinal study confirms the feasibility and value of the daily off-isocenter Winston-Lutz test in a high-volume Linac-based SRS/SBRT/SIMT program. The necessity of this daily test has been justified by the rich informative data generated by this test. The off-iso spatial discrepancy information directly benefits the plan designer to optimize arc beam placement angles and refine isocenter selection. We believe our workflows are readily adaptable by other institutes. With continued technological advancement and workflow optimization, the daily off-iso Winston-Lutz test should become the standard QA practice in single- and multi-target SRS/SBRT/SIMT programs to ensure the highest levels of delivery precision and patient care.

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Author Contributions

Junfang Gao initiated the project, in charge of the data collection and drafted manuscript. Yong Peng performed data analysis, graphs generation and editing.

Conflicts of Interest

The authors have nothing to declare.

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