International Journal of Leading Research Publication (IJLRP)
E-ISSN: 2582-8010 ● Website: www.ijlrp.com ● Email: editor@ijlrp.com

Commissioning of the Mobius3d Independent Dose Verification System for Linear Accelerator.

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Abstract
Ensuring the accuracy of radiation therapy treatment plans is essential for patient safety and treatment efficacy and a secondary independent dose verification is an important for quality control. Mobius3D utilizes reference beam data and a collapsed cone convolution algorithm to calculate three-dimensional (3D) patient dose and automatically analyze dose-volume histograms. To verify its accuracy, we compared Mobius3D calculations with ion chamber measurements in an RW3 Slab Phantom for 50 helical intensity-modulated radiation therapy (IMRT) plans,[1] yielding an average dose difference ratio of −0.2 ± 0.6%. Additionally, 100 treatment plans across various anatomical sites were evaluated by comparing Mobius3D calculations with those from the treatment planning system (TPS), focusing on dose indices and 3D gamma passing rates. Based on these results, action and tolerance levels for the planning target volume (PTV) at each treatment site were determined as $\mu \pm 2\sigma$ and $\mu \pm 3\sigma$, respectively. The average gamma passing rate using a 3%/3 mm criterion was 99.8 ± 0.35%. We also established action and tolerance levels for both the PTV and organs at risk across all treatment sites. Mobius3D[11] provides an accurate secondary dose verification system that can be efficiently commissioned after installation. Before clinical implementation, it must be commissioned using patient-specific treatment plans from each institution to validate calculation accuracy and establish site-specific tolerances. Before clinical use, the Mobius3D system needs to be commissioned using the treatment plans for patients treated in each institution to determine the calculation accuracy and establish tolerances for each treatment site and dose index.

Keywords: commissioning, independent verification, Mobius3D, tolerance, Linear Accelerator, Varian TrueBeam.

INTRODUCTION

In Accurate dose calculation is the cornerstone of safe and effective radiation therapy. Even minor discrepancies in treatment planning can compromise tumor control or cause unintended harm to healthy tissues, making independent secondary dose verification an essential safeguard in radiation therapy quality assurance (QA).

Traditionally, independent dose verification has relied on monitor unit (MU) calculations, which use water phantom measurements to validate the MU values generated by the treatment planning system (TPS). However, this method requires extensive time and resources for data collection and verification. Moreover, because both the TPS and the verification system use the same measurement data, any errors in data acquisition can propagate across both systems, limiting the independence of the verification process. Additionally, traditional MU-based methods rely on simplified dose calculation algorithms, restricting

their accuracy to single-point dose validation under homogeneous conditions.

With the widespread adoption of intensity-modulated radiation therapy (IMRT)[1,9], more sophisticated verification methods are needed. Modern linear accelerators, such as the Varian TrueBeam (Varian Medical Systems, Palo Alto, CA, USA), employ a tertiary multi-leaf collimator (MLC) to deliver highly conformal dose distributions. These complex beam configurations challenge the accuracy of traditional verification techniques, as MU-based validation alone is insufficient when MLC-defined field shapes continuously change during treatment.

IMRT verification is commonly performed using measurement-based techniques, where water-equivalent phantoms embedded with detectors (such as ion chambers, film, or detector arrays) are used to compare the delivered dose with the planned dose [2,3.] However, these methods fail to account for patient-specific anatomical variations and tissue heterogeneity. The simplifications introduced in phantom-based QA disrupt the link between the treatment plan and the verification plan, potentially missing critical errors in patient dose calculations. While Monte Carlo-based dose calculation methods offer greater accuracy, their computational complexity makes them impractical for routine clinical use.

To address these limitations, Mobius3D (Varian Medical Systems, Inc., Palo Alto, CA, USA) has emerged as a next-generation solution for independent dose verification[8,11]. Mobius3D calculates a full three-dimensional (3D) patient dose distribution directly from computed tomography (CT) datasets, utilizing data from the RT Plan, RT Structure, and RT Dose received via DICOM from the TPS. It then automatically compares its calculated dose to the TPS output, generating pass/fail results based on dose-volume histogram (DVH) limits and 3D gamma passing rates. The system provides users with a range of analysis tools, including DVHs, dose indices, 3D dose distributions, dose profiles, and gamma distributions, all accessible through a web-based interface.

Mobius3D offers key advantages over traditional verification methods[8]. Unlike measurement-based techniques, it does not require machine-specific data collection for commissioning, allowing for immediate implementation. Furthermore, it employs a collapsed cone convolution superposition algorithm[6], optimized with graphics processing unit (GPU) acceleration[5], to deliver high-precision dose calculations, even in heterogeneous conditions. These capabilities enable robust and independent validation of TPS dose calculations while providing comprehensive 3D dose distribution analysis.

However, before Mobius3D can be fully integrated into clinical workflows, it must undergo rigorous commissioning to ensure its accuracy and establish site-specific tolerances. This study evaluates the precision of Mobius3D dose calculations for the Varian TrueBeam linear accelerator and defines action and tolerance levels necessary for safe and reliable clinical implementation. By validating Mobius3D's performance across a range of treatment scenarios, this work aims to reinforce confidence in its role as a powerful tool for secondary dose verification in modern radiation therapy.

METHODS AND MATERIALS

A. Mobius3D system for Linac[8,11]

For this study, we employed an RW3 Slab Phantom (PTW) specifically designed for our Varian TrueBeam Linac. This 30cm x 30cm square phantom accommodates a cylindrical ion chamber, allowing for point dose measurements at various depths. Fifty helical IMRT treatment plans encompassing a range of anatomical sites were selected from our institution's patient database. Treatment plans were generated using Eclipse version 16.10, adhering to our established clinical dose constraints. Subsequently, DICOM datasets of these plans were exported and imported into Mobius3D for independent dose calculations. A

0.01 cc PTW pinpoint ionization chamber was utilized to measure point doses within the PTVs of the phantom-based plans. Measurements were confined to regions exhibiting low dose gradients within the PTV[3]. The dose difference ratio was determined by comparing the measured dose to the doses calculated by the treatment planning system (TPS) and Mobius3D, using the following formula:

Dose difference ratio=((Dcalc−Dmeas)/Dmeas)×100[%] (1)

where Dcalc is the dose as calculated by Mobius3D or Planning System, and Dmeas is the dose as measured using the ion chamber. Gamma analysis was performed using the Varian Eclipse portal dosimetry system. Each dose distribution was normalized to the mean dose within the PTV. Gamma analysis employed a 3%/3 mm criteria, representing a 3% dose difference relative to the global maximum dose and a 3 mm distance-to-agreement, respectively, with a 10% threshold to exclude low-dose regions. For both the dose difference ratios and gamma passing rates, the mean (μ), standard deviation (σ), maximum (Max), and minimum (Min) values were calculated.

B. Clinical implementation

To compare the dose calculations between Mobius3D and the Planning Station in a clinical setting, we recalculated treatment plans using Mobius3D for patients previously treated at our institution. The prescription protocol ensured that 95% of the planning target volume (PTV) received the prescribed dose. Mobius3D computed the three-dimensional (3D) dose distribution without renormalization. The following dose indices were analyzed: for the PTV—Dmean, D2%, D50%, D95%, and D98%; for the rectum—Dmean, V65Gy, and V40Gy; and for the bladder—Dmean, V65Gy, and V40Gy.

To evaluate the 3D dose distribution, we performed 3D gamma analysis for the criteria of 3%/3 mm with a 10% threshold. We calculated the four indices μ, σ, Max, and Min for each dose difference ratio.

C. Action and tolerance level

The action and tolerance levels for the dose differences between Planning Station and Mobius3D were set at $\mu \pm 2\sigma$ and $\mu \pm 3\sigma$, respectively. We calculated the mean dose for the PTV at each treatment site and the mean dose for the OAR at all treatment sites.

RESULT

A. Dosimetric verification

Table 1 presents the differences between ion chamber measurements and dose calculations performed by Mobius3D and the Planning System[7,10]. This comparison was conducted at a specific point within the planning target volume (PTV)[2], with mean values reported. The dose difference ratio [$\mu \pm \sigma$ (Min to Max)] was −0.02 ± 1.25% (−1.55 to 1.92) for Mobius3D and −0.16 ± 1.9% (−2.77 to 2.44) for the Planning System. These results indicate that the Planning System slightly underestimated the dose compared to ion chamber measurements, while the standard deviation was comparable between both systems.

Table 2 summarizes the gamma passing rates using the 3%/3 mm criteria[4], comparing dose measurements from Varian portal dosimetry with calculations from Mobius3D[2]. The average gamma passing rates were 99.8 ± 0.35% (94.6 to 100.0) for Mobius3D and 99.5 ± 0.81% (97.7 to 100) for portal dosimetry[10]. Although both methods demonstrated high passing rates, portal dosimetry results were slightly lower than those obtained with Mobius3D. Gamma evaluation failures were primarily observed in high-dose gradient regions adjacent to the PTV and in low-dose areas within organs at risk.

TABLE 1. Summary of differences between measurements using ion chamber and calculations by TPS and Mobius 3D.(% Difference)

Treatment site	TPS	M3D
Mengioma	2.44	-1.46
CA Larynx	-2.77	1.88
Ca Lung	1.25	-1.28
Ca Lung	1.71	-1.55
GBM	-1.73	1.92
Endometrium	2.18	-1.07
Breast	-0.36	0.8
CA Tongue	-2.45	0.45
Pancreas	-2.05	0.4
Buccal Mucosa	0.15	0.07

Statistical Indices

M	-0.163	0.016
σ	1.896	1.247
Max	2.44	1.92
Min	-2.77	-1.55

TABLE 2. Summary of the gamma passing rates between measurement using Portal Dosimetry and Mobius3D.

Gamma passing rates (the criteria of 3%/3 mm) (%)		
Treatment site	Portal Dosimetry	M3D
Mengioma	99.87	99.9
CA Larynx	99.4	99.8
Ca Lung	99.4	99.8
Ca Lung	99.9	100
GBM	100	100
Endometrium	99.7	99.9
Breast	97.1	98.8
CA Tongue	99.9	100
Pancreas	99.8	100
Buccal Mucosa	99.6	99.92

Statistical Indices

μ	99.467	99.812
σ	0.813	0.345
Max	100	100
Min	97.1	98.8

B. Clinical implementation

Figure 1 illustrates the mean dose-volume histogram (DVH) calculated by Mobius3D and the Planning System for a pelvic treatment site. Compared to the Planning System, Mobius3D yielded slightly higher and less homogeneous dose distributions within the PTV.

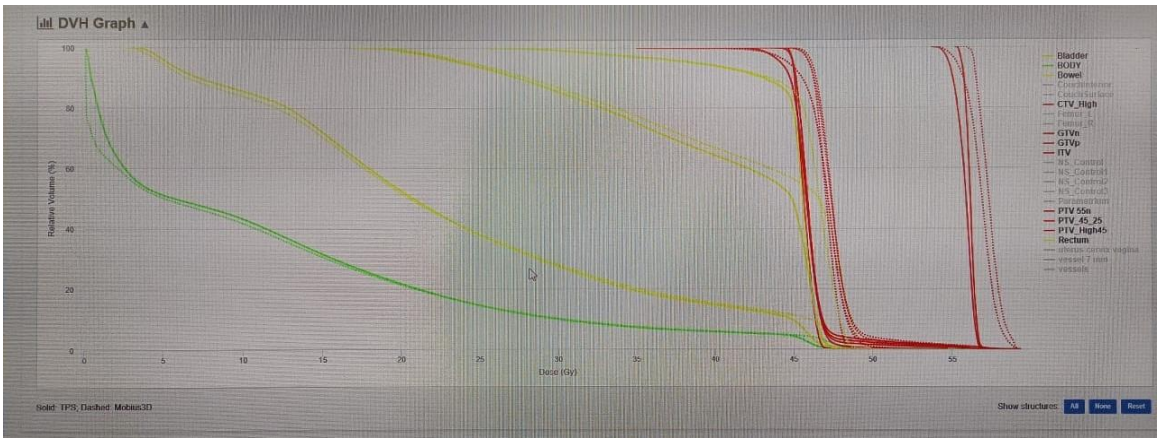

FIG 1. The mean dose-volume histogram calculated by Mobius3D (M3D) and Planning System (TPS) at pelvis

Table 3 summarizes the differences in dose indices between Mobius3D and the Planning System. Notable variations were observed in D_2% for the PTV across all treatment sites. For organs at risk (OARs), the differences in DVH indices remained within 5% and were predominantly within 3%[2].

Additionally, as shown in Table 1, the Planning System's calculated dose was approximately 2.7% higher than the measured ion chamber dose. This finding underscores the impact of commissioning accuracy on independent dose verification results, emphasizing the need for precise calibration of each system to ensure reliable dose validation.

TABLE 3. Summary of the differences in dose indices between Mobius3D and Planning System (TPS)

Structures	Dose indices	Difference (%) Pelvis μ ± σ
PTV	D mean	2.1 ± 0.5
	D 2%	3.4 ± 0.4
	D 50%	2.2 ± 0.4
	D 95%	1.9 ± 0.4
	D 98%	2.3 ± 0.3
Rectum	D mean	0.8 ± 0.5
	V 65Gy	0.7 ± 0.6
	V 40Gy	0.6± 0.8
Bladder	D mean	0.9 ± 0.4
	V 65Gy	1.3 ± 0.6
	V 40Gy	0.8 ± 0.3

The action and tolerance levels, which was set at $\mu \pm 2\sigma$ and $\mu \pm 3\sigma$, respectively, for the mean dose discrepancies between Mobius3D and Planning System.

DISCUSSION

This will make the verification system independent of TPS and immediate clinical implementation possible[7,9]. However, for accurate verification, it is important to ensure that the linear accelerator's beam data at the user's institution agrees with Mobius3D's reference data. In this work, we have commissioned Mobius3D for the linear accelerator by following the methodology given in the Mobius3D User Manual. The vendor recommends adjusting the parameters when the dose difference between the ion chamber measurements and the Mobius3D calculations is greater than 2%. These parameters were tested for various treatment sites. Even though there are only three tuneable parameters in Mobius3D, no apparent disagreement was observed for both point dose and planar dose comparisons during our phantom study. On the contrary, the Planning System under-dosed the point doses consistently when compared with the measurements. For some of the cases, gamma passing rates were also reduced for portal dosimetry when compared with Mobius3D, as reported in Table 2.

For a completely TPS-independent check, manufacturer-developed implementations are incorporated in Mobius3D[7]. Among those implementation differences, one important factor is that Mobius3D involves MLC leakage consideration at 0.25%, whereas such a consideration is not incorporated in the Planning System. Besides, Mobius3D assumes a source size of about 1 mm, while the Planning System models a point source. These parameters, established by Monte Carlo simulations and direct measurements in previous studies, resulted in more pronounced differences in pelvic lymph node cases, where source size influenced the penumbra shape and MLC leakage affected OAR doses.

We also compared Mobius3D and the Planning System for dose-volume histogram metrics, dose indices, and 3D gamma passing rates based on treatment plans for patients treated at our institution. Generally, Mobius3D produced slightly higher and less homogeneous dose distributions compared to the Planning System. These are all expected due to some discrepancies in commissioning accuracy, beam data, calculation algorithm specifications, and CT-PD conversion tables between the two systems. Such factors reflect the discrepancy owing to commissioning accuracy and beam data in Table 1 in the phantom study, where higher point dose values are generated in PTV by Mobius3D as compared to the Planning System.[4]

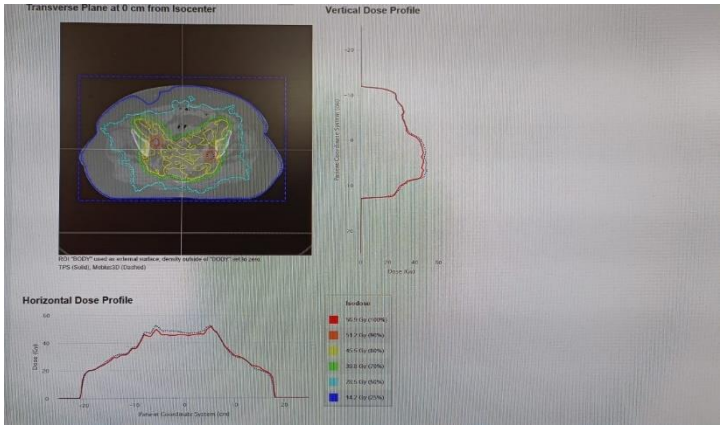

FIG 2. Isodose distributions at cervix case calculated by Planning System and & Mobius3D, and dose profiles (solid TPS & Dashed Mobius3D).

Calculation accuracy in heterogeneous conditions also affected patient study results. Figure 3 presents isodose distributions and dose profiles for a cervix case calculated using the Planning System and

Mobius3D. The dashed line represents Mobius3D, while the solid line corresponds to the TPS. The Planning System adequately covered the PTV with the prescription dose, while Mobius3D presented undercoverage in low-density regions and localized hot spots in surrounding tissues. These differences arise from the very different ways the two systems perform heterogeneity corrections within the PTV, reflecting a fundamental difference in dose calculation philosophy, as shown in Figure 3 dose profiles.

In this phantom study, we demonstrated that Mobius3D yields higher accuracy than the Planning System because more complicated parameters, such as MLC leakage and source size, are implemented in the former. However, the accurate dose calculation in patients also requires proper conversion of CT numbers to density by the system besides effective handling of dose calculation in heterogeneous conditions.

There are no established recommendations on how to set action and tolerance levels for a 3D secondary independent verification system. Thus, it was suggested that institutions should establish appropriate action levels based on non-IMRT MU verification. Indeed, Figure 2(a) illustrates that the average doses for the two systems were discordant in different treatment sites between TPS and a 3D secondary independent verification system. It does point out, however, that users need to scrutinise data for individual treatment sites and dose index during setting action and tolerance levels for 3D-independent verification. Overall, all tolerance levels were within 5% of the total uncertainty, generally accepted as an indicator of adequate radiation treatment.

Patient-specific quality assurance demands systems able to comprehensively monitor every process in a treatment to isolate failures that may occur with patient harm. Apart from the treatment planning verification by using Mobius3D, one needs to check data transfer from the TPS to the linear accelerator control system and hardware malfunctioning during irradiation. Very recently, a different approach was taken in that the system checks the dose distribution by comparing doses calculated by TPS with the ones reconstructed from linear accelerator data after irradiation. Besides Mobius3D, Varian Medical Systems offers another solution, MobiusFX, which embeds this new methodology for advanced dose verification.

CONCLUSION

Our experience in commissioning Mobius3D for the Varian TrueBeam Accelerator demonstrates that Mobius3D provides adequate accuracy for an independent dose verification in our institution. It can be easily commissioned and put into clinical use right away following its installation. We have established action and tolerance levels for clinical implementation, and the 3D secondary independent verification system offers far more detailed and useful information for both targets and organs at risk than previous methods. However, to ensure the reliability of dose calculations and verify plan acceptability, each institution must commission the system thoroughly. This involves determining the calculation accuracy and setting appropriate tolerances at each treatment site and dose index, based on real patient treatment plans. Only then, when properly commissioned and tolerances set, can confidence be had in using the system for clinical decision-making.

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