# Validation of a Newly Installed Secondary Independent Dose Verification System

Philip Kioko Ndonye[1,2] and Samuel Nii Adu Tagoe[3]

[1] *Oncology & Cancer Treatment Centre, The Nairobi Hospital, 20723, Code. 00100, Nairobi, Kenya*
[2] *Cancer Treatment Centre, Kenyatta National Hospital (KNH), 20723, Code. 00202, Nairobi, Kenya*
[3] *Korle Bu Teaching Hospital, School of Biomedical & Allied Health Sciences, University of Ghana, KB 369, Korle Bu, Accra, Ghana*

E-mail: pkndonye@yahoo.com

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**Abstract:** The aim of the study was to validate a newly installed Mobius 3D (M3D) quality assurance software for use as a secondary independent dose verification system for comparison with an Eclipse treatment planning system (TPS) data of 3D conformal radiotherapy treatment (3D CRT). It is recommended that a secondary MU/dose calculation using a secondary method other than the TPS be performed. A total of 138 treatment fields resulting from 103 patients were planned on the TPS for treatment by 3D CRT. The treatment plans data created on the Eclipse TPS were then exported to the M3D independent verification system and results for both systems were compiled as the output of the M3D system. Percentage 3D Gamma passing rate, mean PTV and OAR dose, the percentage difference between PTV and OAR dose for both systems were generated on the M3D secondary system and the results analyzed. The 3D Gamma passing rates for the 138 patient fields verified had been analyzed graphically and had a mean gamma passing rate of 98.7±0.6 %. For a treatment plan verification to be acceptable, a minimum gamma passing rate of 95% needs to be achieved. The percentage Gamma passing rates for the patients were well above the minimum acceptable limit of 95% as seen on the graphical results. 3D Gamma passing rates for the 138 patient treatment fields analyzed and verified had a mean passing rate of 98.7±0.6 % which was well above the minimum acceptable limit of 95% and in agreement with published data. The PTV and OAR data for the percentage difference between M3D and TPS were within Action and Tolerance levels determined and thus the M3D system was validated as a secondary independent treatment plans checker for the Eclipse TPS treatment plans at the institution.

***Keywords****: Action and Tolerance levels, Gamma passing rate, Percentage difference*

## 1. Introduction

Several dose verification systems have been used for dosimetry verification of both treatment plans and delivered doses in external beam radiotherapy (EBRT).

Mobius3D (Varian Medical Systems, Inc., Palo Alto, CA, USA)[1-3] is a software model for quality assurance (QA) application in EBRT. It is an independent verification QA checker of the dose per monitor unit (MU) to deliver the prescribed dose to a patient.

In particular, it is among the new secondary dose verification software systems that are now commercially available to verify dose calculations[3]. In our study, Mobius 3D (M3D) independent secondary software system would be used for routine MU/dose verification of IMRT/VMAT treatment plan checks. The aim of a routine pretreatment verification procedure is to identify and resolve any errors before patient treatment. For IMRT, verification

 

measurements are commonly used to verify the correct delivery of treatment plans, for example with ionization chambers, films, or multidimensional detector arrays.

Apart from Mobius 3D, other commercially available secondary independent software that supports IMRT and VMAT dose/MU QA verification checks include RadCalc (Lifeline Software Inc.), MUCheck (Oncology Data Systems. Inc.), IMSure (Standard Imaging. Inc.), Diamond (PTW Freiburg), DoseCHECK (Sun Nuclear, Corp) and DosimetryCheck (Math Resolutions LLC). Some of this software is also able to support other treatments like Tomotherapy and CyberKnife.

Mobius 3D (M3D) calculates three-dimensional (3D) dose distribution for a patient using computed tomography (CT) datasets that employ information from the radiotherapy plan after receiving the Dicom CT datasets, RT plan, RT structures, and RT dose from the TPS. Following these calculations, M3D automatically compares the dose computed by the TPS with that calculated by M3D. Finally, M3D indicates pass/fail results for the dose-volume-histogram (DVH) limits and the 3D gamma passing rate[4,5].

There are several ways that a user can apply to check the results, for example, DVH dose index, 3D dose distribution, dose profile, and gamma distribution[1]. Some of the advantages of M3D over other secondary systems include the utilization of reference beam data, immediate installation, and the use of collapsed cone convolution superposition algorithm accelerated through graphics processing units for the dose calculation[6,7]. The M3D algorithm can produce accurate calculations for IMRT and for heterogeneous conditions[8].

M3D is generally used for quality assurance, treatment plan verification, and patient alignment and anatomy analysis in radiation therapy. It calculates 3D radiation dose in the representation of a patient or phantom. The dose calculation is based on read-in treatment plans that are initially calculated by a TPS. M3D is not a TPS but for use by trained radiation oncology personnel as a secondary independent quality assurance tool.

In radiation therapy, a secondary independent dose verification of the treatment planning system calculations is an essential part of the quality assurance (QA) process[13]. It is recommended that a secondary MU/dose calculation using a secondary method other than the TPS be performed[15]. In order to bridge the current gap, M3D was used as a secondary independent dose verification system for comparison with an Eclipse TPS data of 3D conformal radiotherapy treatment (3D CRT). Verification for IMRT is usually performed using measurement-based techniques[9] which use water equivalent homogeneous phantoms with detectors (ion chamber, film, detector arrays, etc.) to verify that the dose delivered is the dose planned. This phantom, however, does not represent the actual patient geometry or tissue heterogeneity, and thus a break between the treatment plan and the QA plan. Given different workflows and available resources, each institution should perform independent assessments of the best methods to identify errors and to avoid treatment delays. Therefore, there is a need to have reasonable predictive models for plan evaluation, to improve tumor control, and to predict and hopefully prevent normal tissue injury

However, M3D provides a second check of the treatment plan before the patient treatment and gives information on clinical decision making because of the limitation and uncertainties of TPS[10,11].

## 2. Materials and methods

Accuracy of dose calculation from a verification system needs to be commissioned and validated before clinical use[1] Action and tolerance levels for clinical implementation have been indicated previously[1]. Since there were no guidelines at our institution for setting action and tolerance levels for a 3D secondary verification system, we initiated this work to set action and tolerance levels for our M3D secondary verification system. Action and tolerance levels for 138 fields planned and treated by 3D CRT were verified by M3D and set at $\mu \pm 2\sigma$ and $\mu \pm 3\sigma$ respectively, where $\mu$ is the mean and $\sigma$ the standard deviation of the percentage difference between the M3D and Eclipse TPS. The established action and tolerance levels for PTV and OAR were for cervical, breast, neck, esophagus, prostate, brain, and lung treatment sites.

An Eclipse TPS (Varian Medical Systems, Inc., Palo Alto, CA, USA)[3] for the development of EBRT treatment plans has been in use for several years in our cancer treatment department. 3D CRT treatment technique was used with 6MV and 15 MV linear accelerator (Varian Clinac 2300CD) photon beam energies for the EBRT.

We installed the M3D as a secondary and independent dose verification system for comparison checks with the Eclipse TPS.

After a patient's treatment plan has been created and finalized on the Eclipse TPS, it would be sent to the M3D system for its own independent dose calculation and then the creation of a comprehensive comparison report including dose-volume metrics, gamma, and coverage statistics. The end-user can specify warning and out-of-tolerance levels for mean dose and 95% target coverage as well as the percentage 3D gamma pass-rate. The dose-volume-histogram (DVH) constraints are taken from the literature (RTOG Publications)[17-19]. A flow chart of the whole process of the secondary MU/dose verification by the M3D software system has been included in Figure 1 below.

The target coverage compares the TPS calculated dose to the M3D dose for any structures identified as target regions of interest (ROIs). The M3D target coverage table presents information on mean dose, percentage target coverage, and percentage difference (TPS and M3D dose levels) among other variables calculated[13,14].

DVH limits section of the M3D calculations shows if the plan meets the recommended guidelines for allowable dose/volume in anatomical structures. Independent TPS and M3D pass/alert evaluations are made with respect to the DVH limits defined for different types of anatomical ROIs. Alerts are only triggered by a failure to meet DVH limits but not by a difference between the TPS and M3D computed values. DVH limits can be customized as required but the default DVH limits are from RTOG guidelines for conventional fractionation and from AAPM TG-101[16] guidelines for SRS/SBRT fractionation. A DVH graph window is also available where one can analyze DVH curves for all the structures imported from the plan. M3D generates a pair of DVH curves for each structure. One curve is generated by the dose distribution calculated by the TPS while the other is generated by the dose calculated by M3D. One is now able to compare the TPS and M3D computed DVHs in structures of interest.

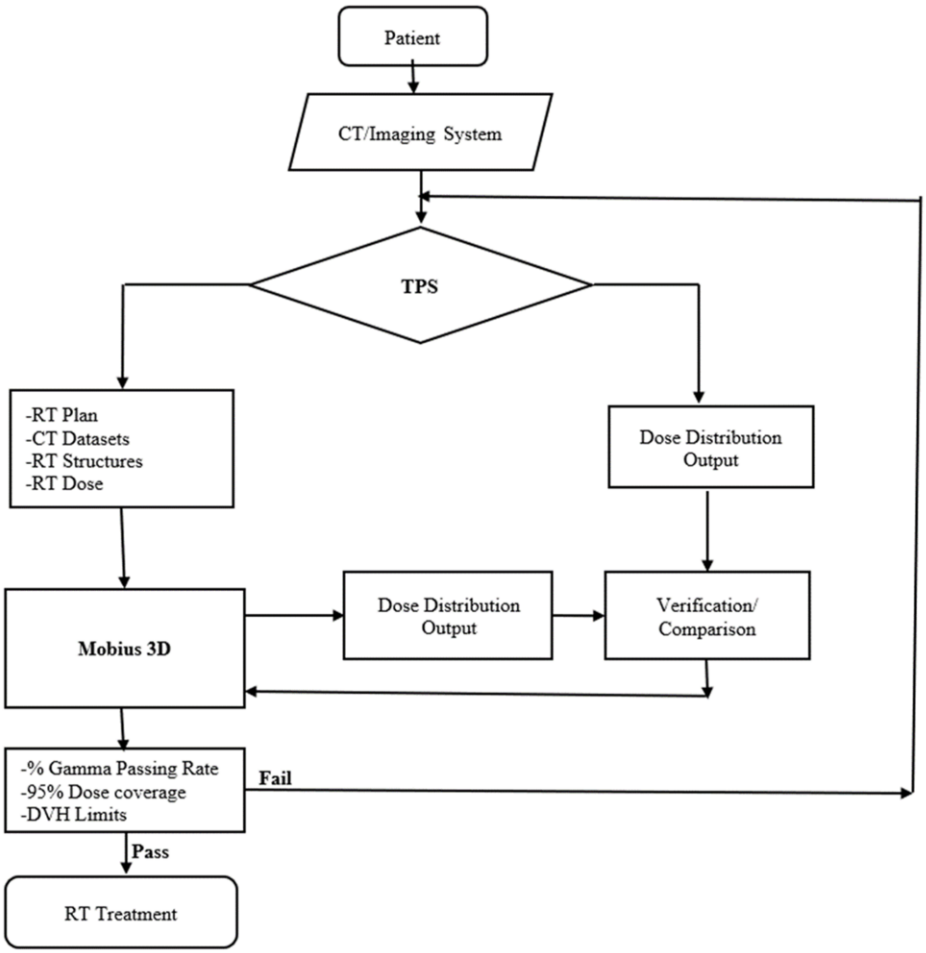


**Figure 1**. Flow chart of secondary MU/dose verification process for Mobius 3D.

The 3D Gamma passing rate is the result of the calculated full 3D gamma comparison between TPS and M3D dose distribution over the entire dose calculation volume. The 3D gamma values would be displayed with a negative value if the M3D dose is lower than the TPS dose. The criteria for the 3D gamma are the dose/distance used in the gamma calculation.

A total of 138 fields (103 patients) planned on Eclipse TPS and treated by 3D CRT on 6MV or 15MV photon energy beams were subjected to M3D verification. The patients are composed of cervical cancer (44), breast (23), esophagus (13), neck (10), prostate (5), brain (5), and lung (3).

## 3. Results and discussion

As with any system used in the clinical treatment of patients, the secondary dose/MU verification system requires commissioning and ongoing quality control monitoring to ensure the accuracy and efficacy of the system as recommended by AAPM TG 53 and AAPM MPPG 5A.

After commissioning, the M3D secondary independent dose verification system is suitable for patient-specific treatment plan QA applications and can be applied for most available EBRT treatment techniques for use with standard linear accelerators. Apart from the limitations of the current paradigm of calculating dose to a single point, a full 3D verification of treatment plans has its own advantages, one of them being to enhance current clinical practice[12].

The secondary verification system data was applied for comparison with dose calculation data from the Eclipse TPS. The patients verified were those treated in the department by the 3D CRT technique. Treatment plans data created on the Eclipse TPS were exported to the M3D independent verification system and results for both systems were compiled as the output of the M3D system.

Percentage 3D Gamma passing rate (at 3% and 3mm criteria), mean PTV dose, mean OAR dose, and percentage difference (% Diff.) for both systems were generated on the M3D secondary system and the results analyzed. All the above variables were available on the regions of interest (ROI) overview window.

The % Diff. is defined as,

$$\%Diff = \frac{M3D\ dose - TPS\ dose}{Reference} \times 100\% \quad (1)$$

The results of the percentage difference of PTV and OAR have been plotted below on graph Figure 2, together with the 5% maximum limit.

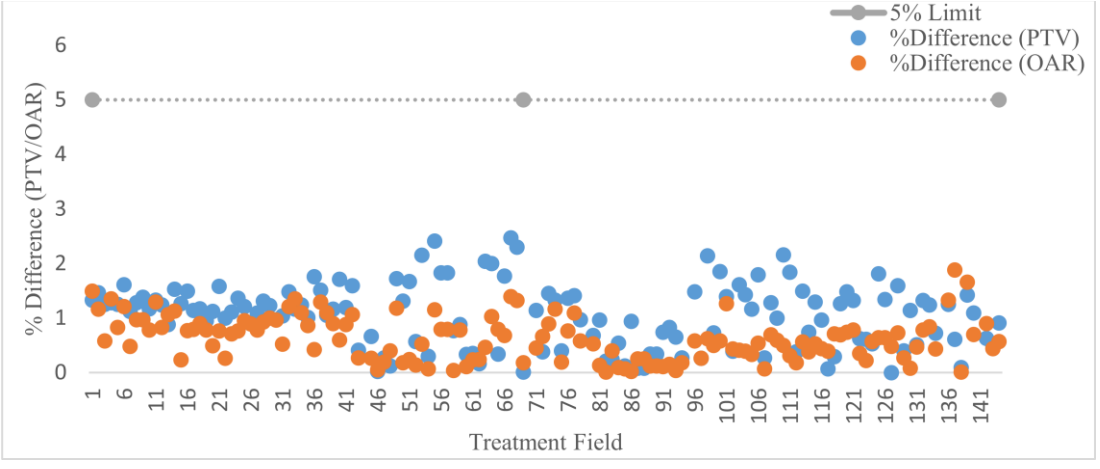


**Figure 2**. Percentage difference between doses calculated by Mobius3D and Eclipse TPS for PTV and OAR of 138 fields treated by 3D CRT technique

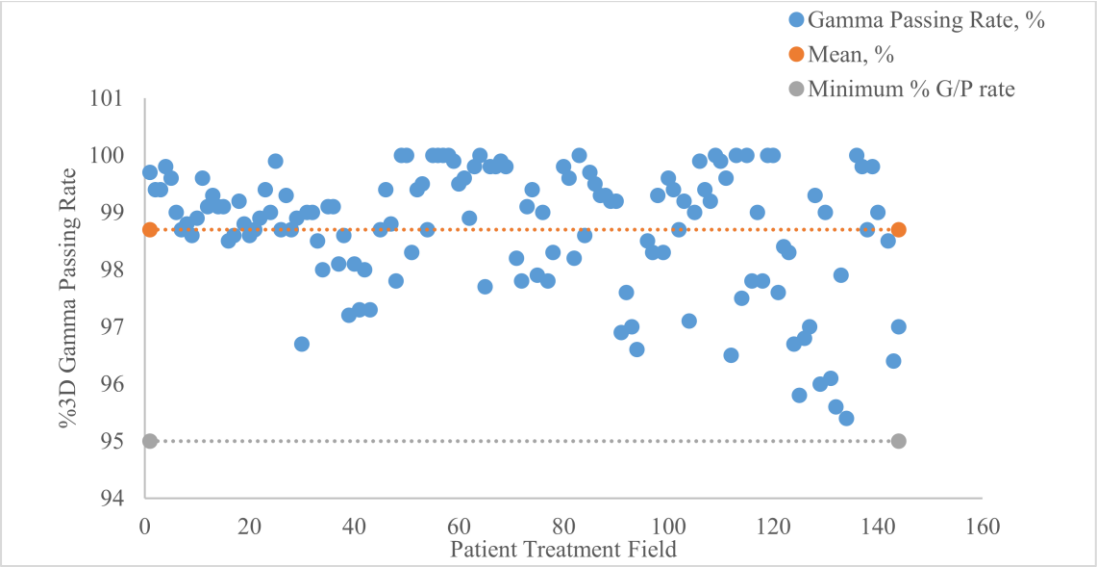


**Figure 3**. Percentage 3D Gamma passing rates for 138 patient fields verified by Mobius3D secondary independent verification system.

Since there are no set guidelines for setting action and tolerance limits for a 3D secondary independent verification system, we decided to use data for 3D CRT treatments to set action and tolerance levels for our institution. Verifications based on 3D CRT is a non-IMRT monitor unit check and could be used for setting action and tolerance levels[13].

The determined 3D Gamma passing rates for the 103 patients (138 fields) verified had been analyzed graphically (Figure 3) and had a mean gamma passing rate of 98.7±0.6 %, with the criteria of 3% and 3mm distance, which was in agreement with published results of gamma passing rate with the criteria of 3% and 3 mm on average was 98.8 ± 1.4% using film[1]. Since the minimum pass rate for a treatment plan verification to be acceptable is 95%[2], the percentage Gamma passing rates for the patients were well above the minimum acceptable limit of 95% as seen on the graph Figure 3. The other value that the M3D system verifies is the treatment coverage which should not be less than 95%.

There are currently no published data on commissioning and determining tolerance levels of Mobius3D[1], Action and tolerance levels for the 138 planned fields and treated by 3D CRT were set at μ±2σ and μ±3σ respectively, where μ is the mean and σ the standard deviation of the percentage difference between the M3D and Eclipse TPS. Below is a summary of the Action and Tolerance levels for the total fields analyzed (Table 1).

**Table 1.** Action and Tolerance levels results for PTV and OAR.

| M3D and TPS | Mean, μ | Standard Deviation, σ | Action Level, μ±2σ | Tolerance Level, μ±3σ |
|---|---|---|---|---|
| % 3D Gamma passing rate | 98.7 | 1.1 | UB: 100; LB: 96.4 | UB: 100; LB: 95.4 |
| % Difference (PTV) | 1.05 | 0.57 | UB: 2.19; LB: -0.09 | UB: 2.75; LB: -0.66 |
| % Difference (OAR) | 0.63 | 0.36 | UB: 1.35; LB: -0.09 | UB: 1.71; LB: -0.45 |

* UB = Upper bound; LB = Lower bound

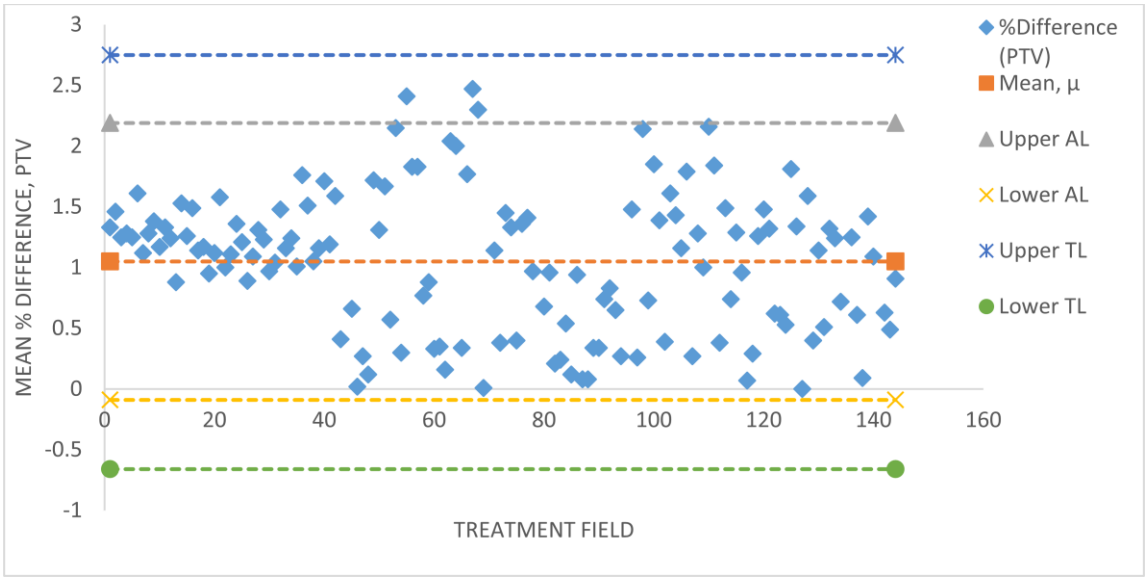


**Figure 4**. Action and Tolerance Level results for PTV

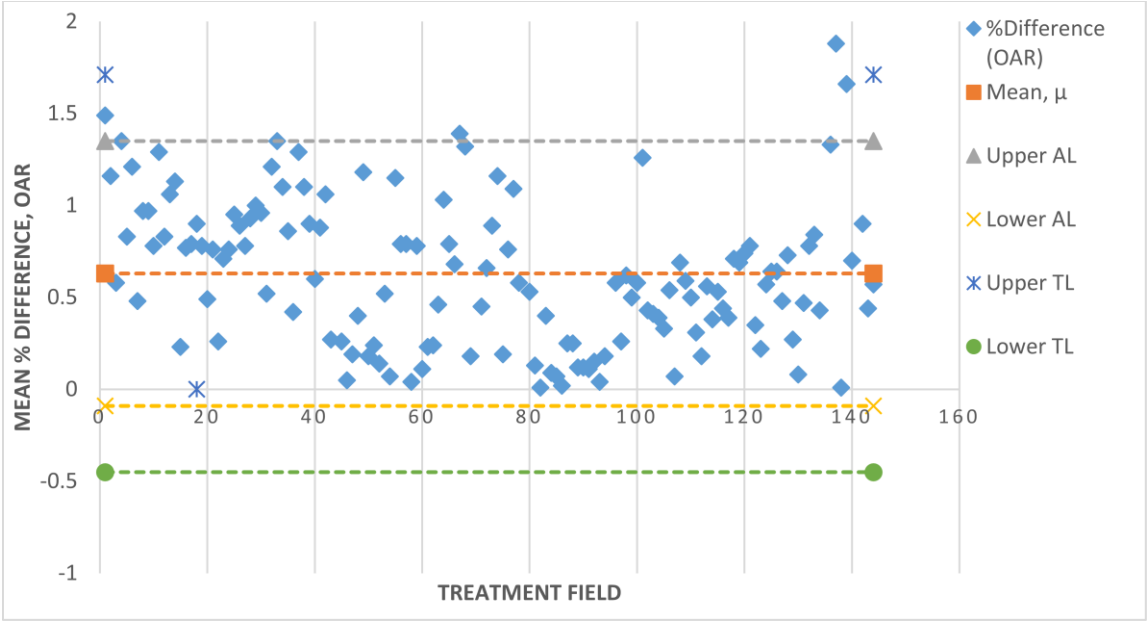


**Figure 5**. Action and Tolerance Level results for the OAR.

Action and Tolerance Levels determined from the 138 patient fields analyzed have been presented graphically in Figure 4 for PTV and Figure 5 for OAR. From the graphs, more than 99% of the PTV and OAR data are within the determined Action levels (μ±2σ), while 100% of the data fall within the determined Tolerance Levels of μ±3σ.

It is recommended that a secondary MU/dose calculation using a secondary method other than the TPS be performed. In order to bridge the current gap, M3D was used as a secondary independent dose verification system for comparison with an Eclipse TPS data of 3D conformal radiotherapy treatment (3D CRT).

**Table 2.** Summary of verification results for the treatment plans considered

| Treatment Plan | Treated Fields | 3D Gamma passing rate, % | Mean % Difference (PTV) | Mean % Difference (OAR) |
|---|---|---|---|---|
| Cervical Cancer | 43 | 98.8 ± 0.7 | 1.24 ± 0.27 | 0.88 ± 0.3 |
| Breast | 39 | 98.3 ± 1.4 | 1.07 ± 0.58 | 0.53 ± 0.24 |
| Head & Neck | 25 | 99.4 ± 0.7 | 1.15 ± 0.85 | 0.53 ± 0.42 |
| Esophagus | 15 | 98.7 ± 1.1 | 0.47 ± 0.3 | 0.16 ± 0.14 |
| Brain | 5 | 99.5 ± 0.5 | 0.89 ± 0.48 | 1.12 ± 0.68 |
| Prostate | 8 | 98.4 ± 0.6 | 1.06 ± 0.41 | 0.72 ± 0.3 |
| Lung | 3 | 97.3 ± 0.9 | 0.68 ± 0.18 | 0.64 ± 0.19 |
| All Plans | 138 | 98.7 ± 1.1 | 1.05 ± 0.57 | 0.63 ± 0.36 |

* UB = Upper bound; LB = Lower bound

The comparisons between the TPS and the secondary dose/MU verification system can be done for each beam and the composite plan dose contribution to a selected point(s). ESTRO Booklet 9103 summarizes the experience of several European institutions and discusses the use of confidence limits. They recommend tolerance limits of 3% for ion chamber measurements in target areas and action limits of 5% for point dose verification.

Our verification measurements were based on point dose verification and the calculated tolerance limit of 2.75% ($\mu\pm3\sigma$) while the action limit ($\mu\pm2\sigma$) was 2.19% of the PTV.

## 4. Conclusion

Apart from treatment dose verification of the TPS dose calculations, M3D now contributes directly to enhancement as a secondary independent dose verification system in 3D verification of the TPS accuracy, as opposed to the applications of single point dose verification by use of point detectors.

3D Gamma passing rates for the 138 fields analyzed and verified had a mean passing rate of 98.7±0.6 %. This was in agreement with other published results of the equivalent study. Since the minimum pass rate for a treatment plan verification to be acceptable is 95%, the percentage Gamma passing rates for the patients were well above the minimum acceptable limit of 95% as seen on the graph and as a result, the M3D system was validated for future secondary dose verifications at the hospital.

More than 99% of the percentage difference data between M3D and the Eclipse TPS were within the Action Levels and 100% fell within the Tolerance Levels determined. This was an indication that $\mu\pm2\sigma$ and $\mu\pm3\sigma$ could be applied as Action and Tolerance Levels respectively, for acceptance or rejection of a patient plan and thus the above Action and Tolerance Levels were validated for application at the institution. Mobius3D calculations thus provide an accurate secondary dose verification system that can be commissioned easily and immediately after installation.

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## References

[1] Kodama T., Saito Y., Hatanaka S., et al. "Commissioning of the Mobius 3D independent dose verification system for tomotherapy," J. Appl. Clin. Med. Phys. **20**, 12-20 (2019).

[2] Van het Loo M, & Welleweerd J. *3D dose verification of VMAT lung SBRT using Mobius3D*, ESTRO Third Forum, PO-08373 (2015).

[3] Dossel O. & Schlegel W.C., *World Congress on Medical Physics and Biomedical Engineering, September 7 - 12, 2009, Munich, Germany*, IFMBE Proceedings, **25**(11) (2009).

[4] Low D.A, Harms W.B, Mutic S., et al. "A technique for the quantitative evaluation of dose distributions," Med. Phys. **25**, 656-661 (1998).

[5] Low D.A., & Dimpsey J.F, "Evaluation of the gamma dose distribution comparison method," Med. Phys. **30**, 2455-2464 (2003).

[6] Mackie T.J., Scrimger J.W, & Battista J.J, "A convolution method of calculating dose for 15 MV x-rays," Med. Phys. **12**, 188-196 (1985).

[7] Ahnesjo A., "Collapsed cone convolution of radiant energy for photon dose calculation in heterogeneous media," Med. Phys. **16**, 577-592 (1989).

[8] Hasenbalg F, Neuenschwander H, Mini R, et. al., "Collapsed cone convolution and analytical anistropic algorithm dose calculations compared to VMC++ Monte Carlo simulation in clinical cases." Phys. Med. Biol. **52**, 3679 (2007).

[9] Miften M, Olch A, Mihailidis D, et al., "Tolerance limits and methodologies for IMRT measurement based verification QA: Recommendations of AAPM Task Group No.218," Med. Phys. **45**, e53-e83 (2018).

[10] Jolly D, & Dunn L., "A clinical database to assess action levels and tolerances for the ongoing use of Mobius3D," J. Appl. Clin. Med. Phys. **18**, 59-65 (2016).

[11] Dunn L, & Jolly D., "Automated data mining of a plan-check database and example application," J. Appl. Clin. Med. Phys. **19**(5), 739-748 (2018).

[12] Fontenot J.D., "Evaluation of a novel secondary check tool for intensity-modulated radiotherapy treatment planning," J. Appl. Clin. Med. Phys. **15**(5), 207-2015 (2014).

[13] Stern R.L, Heaton R, Fraser M.W, et al., "Verification of monitor unit calculation for non-IMRT clinical radiotherapy. AAPM Task Group No.114," Med. Phys. **38**, 504-530 (2011).

[14] Teichmann T, Salz H, & Schwedas M., "A multi-institutional initiative on patient-related quality assurance: Independent computational dose verification of fluence-modulated treatment technique," Zeitschrift fur Medizische Physik **30**(2), 155-165 (2020).

[15] Xia P, Sintay BJ, Colussi VC, et al., "Medical Physics Practice Guideline (MPPG) 11.a: Plan and chart review in external beam radiotherapy and brachytherapy," J. Appl. Clin. Med. Phys. **22**(9), 4–19 (2021).

[16] Benedict SH, Yenice KM, Followill D, et al, "Stereotactic body radiation therapy: The report of TG 101," Med. Phys. **37**(8), 4078-4101 (2010).

[17] Knapp P, Eva B, Reseigh G, et al., "The role of volumetric modulated arc therapy (VMAT) in gynaecological radiation therapy: A dosimetric comparison of intensity modulated radiation therapy versus VMAT," J. Med. Radiat. Sci. **66**(1), 44-53 (2018).

[18] Petrović B, Olivera Ivanov O, Marjanović M, et al., "Transition from conformal to advanced radiotherapy techniques in treatment planning of gynecological cancer patients," Vojnosanitetski pregled **1**, 77 (2021).

[19] Jhingran A, Winter K, Portelance L, et al., "A phase II study of intensity modulated radiation therapy to the pelvis for postoperative patients with endometrial carcinoma: Radiation Therapy Oncology Group trial 0418," Int. J. Radiat. Oncol. Biol. Phys., **84**(1), e23-8 (2012).