e-ISSN 2083–4640
ISSN 1507–1367

RESEARCH PAPER

Reports of Practical Oncology and Radiotherapy
2024, Volume 29, Number 1, pages: 62–68
DOI: 10.5603/rpor.99027
Submitted: 24.07.2023
Accepted: 09.01.2024

Optimization of a commercial portal dose image prediction algorithm for pre-treatment verifications of plans using unflattened photon beams

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ABSTRACT

Background: The aim was to improve the portal dosimetry-based quality assurance results of conventional treatment plans by adjusting the multileaf collimator (MLC) dosimetric leaf gap (DLG) and transmission (T) values of the anisotropic analytic algorithm (AAA) used for portal dose image prediction (PDIP).

Materials and methods: The AAA-based PDIP v. 16.1 algorithm (PDIP-AAA) of the Eclipse TPS was configured for 6 MV FFF energy. Optimal DLG and T values were achieved for this algorithm by comparing predicted versus measured portal images of the Chair pattern. Twenty clinical plans using 6 MV FFF beams were verified using the optimal PDIP-AAA algorithm and the standard PDIP v. 16 algorithm (PDIP-vE), configured using the van Esch package. The 3% global/2 mm gamma passing rates (GPRs) and average gamma indexes (AGIs) were computed for each acquired image. For each plan, the mean GPR (GPR_{mean}) and mean GAI (GAI_{mean}) were compared for both algorithms. A 2-tailed Student t-test ($\alpha = 0.05$) was used to evaluate whether there was a statistically significant difference.

Results: Optimal values of DLG = 0.1 mm and T = 0.01 were found for the PDIP-AAA algorithm, providing significantly better values of GPR_{mean} and AGI_{mean} than PDIP-vE ($p < 0.001$). All plans verified with PIDP-AAA showed $GPR_{mean} \geq 95\%$. In contrast, only 45% of the plans reported $GPR_{mean} \geq 95\%$ with the PDIP-vE algorithm.

Conclusions: The MLC parameters available in the PDIP-AAA model must be tuned to improve the accuracy of the predicted dose image. This work-around is not possible using the standard PDIP algorithm. The adjusted PDIP-AAA resulted in significantly better results than PDIP-vE.

Key words: portal dosimetry; PSQA; AAA

Rep Pract Oncol Radiother 2024;29(1):62–68

Introduction

Patient-specific quality assurance (PSQA) is a crucial process intended to check the accuracy of treatment plan dose calculations and to detect clinically relevant discrepancies between calculated and delivered radiation doses.

Physical measurement based PSQA of intensity-modulated radiation therapy (IMRT) treatments are extensively employed and form the fundamental component of most IMRT QA programs. The American Association of Physicists in Medicine (AAPM) Task Group (TG)-218 has provided recommendations on measurement methods

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and tolerance limits for IMRT measurement-based verification QA [1]. A current topic of discussion among medical physicists, is the potential substitution of physical measurements with computational methods [2–4].

Two dimensional (2D) image analysis using the electronic portal imaging device (EPID) is one of the important computational methods often considered for inclusion in the PSQA process [4, 5]. EPID is a perpendicular field-by-field (PFF) method used to measure the 2D the delivery of the dose distribution associated with each field of an IMRT plan. For volumetric-modulated arc therapy (VMAT) plans, the dose is integrated for all the perpendicular fields delivered during each arc, resulting in a single-dose image for each arc. A portal dose image prediction (PDIP) model is needed in the treatment planning system (TPS) to predict the dose distribution at the EPID level to be compared with the measured dose for each field of the plan.

Portal dosimetry with an EPID (Varian Medical Systems, Palo Alto, CA, USA) has been described as an effective tool to verify the delivery of IMRT and VMAT plans [6–9]. However, it is known that the poor performance of the portal imager to low-energy radiation caused by the energy dependence of the EPID (high Z phosphor) response, such that the imager response to the beam spectrum transmitted through closed multileaf collimator (MLC) leaves is much lower than for the open beam spectrum, as indicated in several publications [10, 11]. This issue is more important for 6 MV FFF beams because the flattening filter-free (FFF) open beam produces a softer spectrum of photons than the 6 MV flattening filtered beam. This fact is not considered by the PDIP algorithms of the Varian Eclipse TPS. The Eclipse TPS offers PDIP for 6 MV FFF energy using the anisotropic analytic algorithm (AAA). Lalonde et al. described a simple correction method to improve QA results of cranial stereotactic radiosurgery (SRS) plans using the Varian portal dosimetry. It consists of tuning the dosimetric leaf gap (DLG) and MLC transmission (T) values used in the PDIP-AAA model.

At Hospital Quirónsalud Málaga, the Octavius 4D system (PTW, Freiburg, Germany) is used as the golden standard for PSQA, although it is time consuming and takes valuable treatment time. The portal dosimetry EPID method of PSQA would provide a faster and easier verification. However, based upon recent departmental experience, it has been observed that the classical PDIP algorithm for portal dosimetry produces results that are not consistent with the Octavius 4D measurements, especially for 6 FFF MV plans. The aim of this study is to investigate how the AAA algorithm used for portal dosimetry can be adjusted following the Lalonde's methodology in order to improve the PSQA results of conventional treatment plans with respect to the use of the classical PDIP model [13].

Materials and methods

Stereotactic body radiotherapy (SBRT) of pelvic and abdominal tumors, breast hypofractioned radiotherapy and cranial stereotactic radiosurgery (SRS) are the most common indications treated at Hospital Quirónsalud Málaga using the 6 MV FFF energy. For each of these indications, several random plans were selected to collect a total of 20 plans. All plans were created using the Eclipse v. 16.1 TPS using IMRT (sliding window) or VMAT techniques. Plans were designed with 6 MV FFF photon beams from a Varian TrueBeam linac equipped with a High-Definition (HD) MLC and an aS1200 EPID. The maximum dose rate was 1400 monitor units per minute (MU/min). The algorithm Acuros XB v. 16.1 was used for dose calculation (dose-to-medium). During its commissioning, the DLG and T values required for 6 MV FFF beams were optimized by ionization chamber measurements to achieve calculated-measured dose differences within ±2% for a set of clinical plans. The values obtained were: DLG = 1.25 mm and T = 0.01.

The portal imager was calibrated for dosimetric acquisition following the Varian portal dosimetry calibration procedure. This involved applying a correction using the dark and flood-field method (using a 40 × 32 cm^2 field irradiation), performing an absolute calibration with a 10 × 10 cm^2 field, establishing a correspondence of 100 MU to 1 aS1200 EPID calibrated unit (CU), and applying a beam profile correction. In this study, portal images were always acquired with the EPID set up at the isocenter.

In the Eclipse software, two PDIP algorithms were configured for portal dosimetry verification

of the clinical plans. The first one was configured using the standardized PIDP package developed by van Esch et al. (PDIP-vE) [13]. The second one consisted of the AAA capability for portal dose calculation with an internal model of the portal dose detector (PDIP-AAA). Unlike AAA for patient dose calculations, the AAA portal dose capability uses scatter kernels calculated in the imager scintillator material to predict the appropriate dose response of the detector. To configure the PDIP-AAA algorithm, a new "add on" type "Portal Dose Imager" must be created in Beam Configuration workspace within the AAA algorithm. The same configured AAA beam data can be used for patient dose calculations and portal dose calculations [14].

Although the T and DLG values cannot be modified in the PDIP-vE algorithm, the PDIP-AAA model includes an MLC add-on enabling the tuning of these MLC parameters. Optimization of DLG and T for the PDIP-AAA algorithm was performed by comparing the predicted versus measured portal images for the well-established dynamic Chair artificial IMRT pattern [15]. By trying different DLG and T values in the PDIP-vE algorithm, optimal values were considered when a combination of the maximum 2D gamma passing rate (GPR) and minimum average gamma index (AGI) was found on the gamma index analysis of the Chair test, using the 3% global/2 mm criteria (with a 10% cut dose) as recommended by the AAPM TG-218 report [1]. As a starting point, the values of DLG and T tried in the PDIP-AAA algorithm were derived from EPID measurements using sliding window gaps ranging from 2 to 20 mm, following the methodology described by Mei et al. [16] The optimal DLG and T values found were adopted for configuration of the PDIP-AAA algorithm in order to perform the portal dosimetry verifications of the 20 treatment plans selected in this study.

For each treatment plan, two portal verification plans were created using the PDIP-vE and optimized PDIP-AAA algorithms. Individual portal images were acquired for each of fields in each of the plans, such that both verifications were carried out using the same portal images. Overall, 70 verification fields corresponding to all of the fields used in the 20 treatment plans were irradiated using the EPID system. For each plan verification, the 2D GPR and AGI were calculated for each field, and the values averaged over all fields of each plan were obtained (GPR_{mean} and AGI_{mean}, respectively). A 2-tailed Student t-test ($\alpha = 0.05$) was used to evaluate whether there was a significant statistical difference between the 2D GPR_{mean} and AGI_{mean} values reported by both algorithms over the 20 plans. These plans showed excellent three dimensional 3% global/2 mm gamma passing rates (3D GPRs) ≥ 95% when they were verified with the primary measurement system used at Hospital Quirónsalud Málaga (Octavius 4D, PTW, Freiburg, Germany). Therefore, this indicates that if the tuned PDIP-AAA results have comparable gamma passing rates, they could be considered as a potential replacement for the Octavius 4D measurements in the local PSQA program. A Bland-Altman analysis was also performed to evaluate the agreement between both types of verification [17, 18]. It is a well-established method for quantifying the agreement between two methods of clinical measurement, by using the differences between observations made using the two methods on the same subjects. The 95% limits of agreement (LoA), estimated by a mean difference of ± 1.96 standard deviations (SD) of the differences, provide an interval within which 95% of the differences between measurements by the two methods are expected to lie. The Bland-Altman method is frequently used to assess whether a methodology can replace the standard one without loss of information and/or reduction in accuracy.

Results

Table 1 and Figure 1 show the 2D GPR and AGI values obtained from the Chair pattern analysis by varying the DLG and T values. Test #1 used the DLG and T values derived from the sliding gap-based EPID measurements resulting in the worst agreement between the predicted and actual portal doses. In tests 2 to 5, the DLG was fixed at 0.1 mm and T was varied, while the DLG value was varied by keeping T = 0.01 in the remaining tests. Optimal 2D GPR and AGI values were found for DLG = 0.1 mm and T = 0.01. Table 2 and Figure 2 show the GPR_{mean} and AGI_{mean} values for the verifications of these plans using the PDIP-AAA and PDIP-vE algorithms. Over the 20 treatment plans, the optimized PDIP-AAA algorithm significantly improved the values (mean ± SD) of GPR (99.0% ± 1.2% *vs.* 94.6% ± 5.1%, $p < 0.05$) and AGI

Table 1. Gamma passing rate (GPR) and average gamma index (AGI) for the Chair test by varying the dynamic leaf gap (DLG) and multileaf collimator (MLC) transmission (T) in the anisotropic analytic algorithm of portal dose image prediction (PDIP-AAA). The criteria used were: Global 3%/2 mm and 10%-dose threshold

Test #	DLG (mm)	T	GPR (%)	AGI
1	0.3916	0.006	24.6	1.75
2	0.1000	0.006	94.2	0.51
3	0.1000	0.005	90.0	0.56
4	0.1000	0.001	91.6	0.45
5	0.1000	0.000	94.3	0.28
6	1.2500	0.010	74.7	0.78
7	1.0000	0.010	93.7	0.65
8	0.7000	0.010	96.0	0.44
9	0.5000	0.010	96.9	0.34
10	0.3000	0.010	98.4	0.24
11	0.2000	0.010	99.3	0.21
12	0.1500	0.010	99.8	0.20
13	0.1000	0.010	99.9	0.15

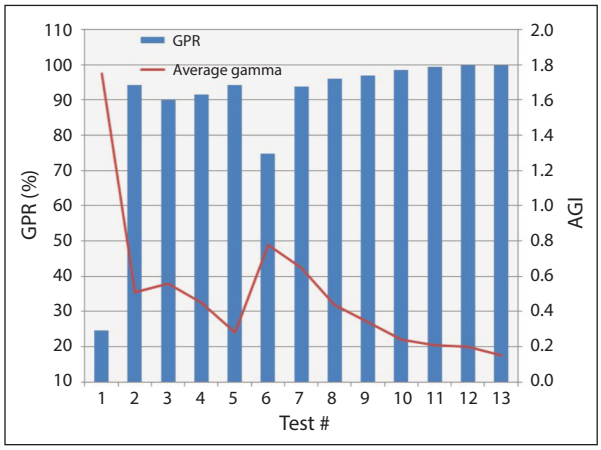

Figure 1. Optimization of the anisotropic analytic algorithm of portal dose image prediction (PDIP-AAA): values of 3%/2 mm gamma passing rates and average gamma index from the Chair pattern analysis for 13 combinations of multileaf collimator (MLC) dosimetric leaf gap (DLG) and T values

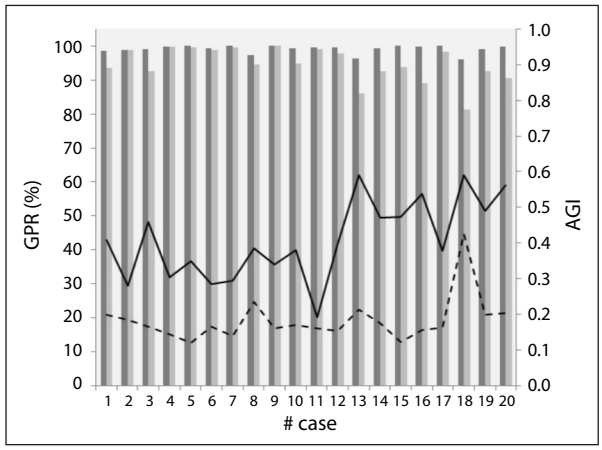

Figure 2. Mean gamma passing rate (GPRmean) and average gamma index (AGImean) reported by the anisotropic analytic algorithm of portal dose image prediction (PDIP-AAA) and PDIP package developed by van Esch (PDIP-vE) algorithms for 20 clinical plans

(0.2 ± 0.1 *vs.* 0.4 ± 0.1, $p < 0.05$) compared to using the PDIP-vE algorithm. The GPR_{mean} reported by the PDIP-AAA algorithm was greater than 95% for all plans, whereas the PDIP-vE algorithm resulted in GPR_{mean} values less than 95% for 11 plans (16%). Ninety-five percent is the universal tolerance recommended by the AAPM TG-218 report for gamma index analysis using global normalization with the 3%/2 mm (10% dose threshold) criteria.[1] A revision of the GPR values over the 70 fields included in the 20 cases indicates that 27 fields were reported with GPR < 95% when PDIP-vE was used for portal dosimetry analysis and only 1 field was reported to be lower than the 95% tolerance when PDIP-AAA was used.

Table 2 shows that all plans with GPR values greater than 95% reported by the Octavius system corresponded to GPR_{mean} values also greater than 95% when the PDIP-AAA algorithm

Table 2. Gamma index analysis for 20 clinical plans using two portal dose image prediction (PDIP) algorithms and the Octavius system. Gamma passing rate (GPR) and average gamma index (AGI) averaged over the fields of each plan are shown. Ranges of both metrics are given between brackets. The criteria used were: Global 3%/2 mm and 10%-dose threshold

Case. Site	Technique	PDIP-AAA		PDIP-vE		Octavius-GPR (%)
		GPR (%)	AGI	GPR (%)	AGI	
1. Vertebrae	VMAT (SBRT)	98.5 [98.4,98.5]	0.2 [0.2,0.2]	93.5 [92.3,94.7]	0.41 [0.39,0.43]	100
2. Panchreas	VMAT (SBRT)	98.8 [98.4,99.2]	0.19 [0.17,0.2]	98.7 [97.6,99.8]	0.28 [0.25,0.31]	100
3. Vertebrae	VMAT (SBRT)	99 [98.2,99.7]	0.17 [0.14,0.19]	92.7 [90.6,94.7]	0.46 [0.43,0.49]	100
4. Lung	VMAT (SBRT)	99.8 [99.7,99.8]	0.15 [0.14,0.15]	99.7 [99.5,99.9]	0.31 [0.3,0.31]	99.9
5. Prostate	VMAT (SBRT)	100 [100,100]	0.12 [0.12,0.12]	99.6 [99.6,99.6]	0.35 [0.35,0.35]	100
6. Lung	VMAT (SBRT)	99.3 [98.5,100]	0.17 [0.14,0.19]	98.8 [98.6,98.9]	0.29 [0.26,0.31]	100
7. Lung	VMAT (SBRT)	100 [100,100]	0.14 [0.12,0.16]	99.6 [99.3,99.9]	0.3 [0.28,0.31]	100
8. Lung	VMAT (SBRT)	97.4 [96.8,97.9]	0.24 [0.22,0.25]	94.6 [94,95.2]	0.39 [0.38,0.39]	99.6
9. Prostate	VMAT (SBRT)	100 [100,100]	0.16 [0.16,0.16]	100 [100,100]	0.34 [0.34,0.34]	100
10. Lung	VMAT (SBRT)	99.2 [99.2,99.2]	0.17 [0.17,0.17]	94.9 [94.9,94.9]	0.38 [0.38,0.38]	99.6
11. Breast	IMRT (SW)	99.5 [97.6,100]	0.16 [0.09,0.27]	99 [95.1,100]	0.19 [0.1,0.36]	97.2
12. Breast	IMRT (SW)	99.6 [98.4,100]	0.16 [0.1,0.2]	97.8 [93.7,99.9]	0.4 [0.32,0.48]	98.9
13. Breast	IMRT (SW)	96.4 [78.2,100]	0.21 [0.1,0.61]	86.1 [40.7,100]	0.59 [0.36,1.19]	96.7
14. Breast	IMRT (SW)	99.2 [97,100]	0.18 [0.1,0.28]	92.4 [76.8,100]	0.47 [0.36,0.6]	99.7
15. Breast	IMRT (SW)	99.9 [99.7,100]	0.12 [0.09,0.16]	93.9 [78.9,99.9]	0.47 [0.31,0.72]	99.3
16. Breast	IMRT (SW)	99.7 [99.2,100]	0.16 [0.11,0.2]	89.1 [78.3,100]	0.54 [0.36,0.68]	98.2
17. Breast	IMRT (SW)	100 [99.8,100]	0.16 [0.12,0.19]	98.3 [92.3,100]	0.38 [0.28,0.54]	98.5
18. Brain	VMAT (SRS)	95.9 [95,96.7]	0.43 [0.37,0.49]	81.3 [69.2,93.6]	0.59 [0.46,0.71]	100
19. Brain	VMAT (SRS)	99 [98.7,99.4]	0.2 [0.15,0.22]	92.5 [86.1,99.5]	0.49 [0.33,0.57]	100
20. Brain	VMAT (SRS)	99.7 [99.6,99.9]	0.21 [0.18,0.24]	90.6 [80.7,95.6]	0.56 [0.48,0.72]	99.9

PDIP-AAA — AAA-based PDIP algorithm tuned with the optimal dosimetric leaf gap (DLG) and multileaf collimator (MLC) transmission values found in this study; PDIP-vE — portal dose image prediction algorithm configured using the standard van Esch's package; SW — sliding Window

was used, which was not accomplished with the PIPD-vE model. The Bland-Altman analysis resulted in a bias of 0.3% and limits of agreement (LoA) of ±3% for the GPR metric, suggesting that the PDIP-AAA method could replace the Octavius-based measurement method for performing routine PSQA at Hospital Quirónsalud Málaga.

Discussion

In this study, the known suboptimal performance of the classical PDIP-vE model for PSQA of 6 MV unflattened modulated plans[11] has been overcome by using and adjusting the PDID model based on the AAA algorithm, as it can be tuned by modifying the values of the DLG and T parameters. This strategy was previously described by Lalonde et al. to improve the AAA-based portal dose prediction for single isocenter VMAT plans for multiple brain metastases [12]. However, these authors did not explore the correction they described for non-stereotactic plans treating larger lesions. In this study, the AAA-based PDIP algorithm was tuned and checked using 20 treatment plans, including common treatments, such as breast and prostate cancer sites, as well as stereotactic treatments for lung and brain targets.

Table 2 and Figure 2 clearly demonstrate that the tuned PDIP-AAA algorithm has significantly improved the GPR_{mean} and AGI_{mean} values in all plans with respect to the classical PDIP-vE model previously used at Hospital Quirónsalud Málaga. The optimal DLG and T values) obtained in this study for PDIP-AAA tuning were 0.1 mm and 0.01, respectively. These optimized PDIP values are unrelated to the respective values (1.25 mm and 0.01) used for the calculation of patient dose distributions by the clinical Acuros AXB algorithm.

The improvement in GPR_{mean} and AGI_{mean} metrics depends on the relative amount of MLC-trans-

mitted dose in each plan [10, 11]. Therefore, the adjusted PDIP-AAA model should be applied to all treatment plans verified using the portal dosimetry tool. Lalonde et al. reported that improvements in QA results to single target SRS plans were not significant [12]. However, a clear improvement was observed in the GPR and AGI values obtained in this study for the single target SRS plan.

Currently, Octavius-based measurements are the gold standard at Hospital Quirónsalud Málaga for PSQA of clinical plans. The Bland-Altman analysis is considered as an appropriate method to decide whether a new method (PDIP-AAA-portal dosimetry in this study) is comparable to the gold standard method (Octavius system). In this study, the Bland-Altman analysis revealed a near zero bias and agreement limits of ±3% between both measuring methods, that is, below the 5% to 10% failing rate permitted by the AAPM TG-218 report when the GPR metric is assessed. In contrast, the Bland-Altman analysis reported a bias of 5% and limit of agreement up to 15% for the classic PDIP-vE algorithm when compared with the Octavius system. Therefore, these results indicate that only the PDIP-AAA model could be used as an alternative to the Octavius system for PSQA performed at Hospital Quirónsalud Málaga.

Following the methodology described in the AAPM TG-119, appropriate confidence limits for the GPRmean and AGImean metrics were set at Hospital Quirónsalud Málaga department. When a treatment plan is verified using the portal dosimetry method (adjusted PDIP-AAA algorithm), these action levels were established: GPRmean > 96% and AGImean < 0.30. In addition, the requirement of GPR > 90% for each field was also established in accordance with the TG-218 report. If the portal dosimetry verification does not meet these action levels, PSQA is repeated using the Octavius device.

Conclusion

The tuning of the MLC parameters (DLG and T) available in the PDIP-AAA model allows the accuracy of the predicted dose image to be improved, resulting in significantly better QA results for conventional treatment plans designed with 6 MV FFF energy. Portal dosimetry using the adjusted AAA model is currently used in the PSQA program established at Hospital Quirónsalud Málaga.

Acknowledgements

I want to thank Dr Adam Jones for reviewing the grammatical English of this manuscript.

Conflict of interests

Author declare no conflict of interests.

Funding

None declared.

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