

HOW TO

QUALITY CONTROL AND PRE-TREATMENT QUALITY ASSURANCE APPLICATION OF EPID (aSi1000) FOR FF AND FFF BEAM VMAT PLANS

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Abstract— Radiotherapy employs high energy radiation for the purpose of cancer treatment. Precise patient positioning is essential with the current use of complicated treatment plans. Portal imaging is often used for pre and during treatment anatomical setup verification. Currently the most advanced and widely used amorphous silicon Electronic portal imaging device (EPID) (aSi 1000) and the TrueBeam linear accelerator (LINAC) from Varian medical systems were used here for the measurements.

Regular QC (quality control) of the EPID with the use of PTW QC phantom to monitor its performance was performed. Instead of EPIDs main purpose in the department, it was aimed to implement it for a fast and efficient way to perform pre-treatment sophisticated treatment plan QAs (quality assurances). EPIDs spatial resolution and features made them well suited for dosimetric purposes. The treatment plans analyzed include flattened (FF) and flattening filter free (FFF) beams with the TrueBeam LINAC capability of delivering both beam types.

Five VMAT plans with 6MV beam in total having ten arc fields were analyzed using both Eclipse integrated portal dosimetry and external EPIQA software. In addition, four VMAT plans with 6MV FFF beam, in total having nine arc fields were analyzed using EPIQA, since the feature is not supported by Varian Eclipse system currently. The aim of the project was to determine the reliability and comparability of the QA methods.

The evaluations were under acceptable tolerance and as a result it was prevalent that the pretreatment QA methods from both EPIQA and Varian for 6MV beams are comparative and reliable. Further, it was evident that EPIQA system could successfully be implemented for pretreatment 6FFF beam VMAT plan QAs.

Keywords— EPID (electronic portal imaging), LINAC (linear accelerator), SDD (source detector distance), VMAT (volumetric modulated arc therapy), dosimetry.

I. INTRODUCTION

The use of a megavoltage energy beam for imaging in radiation therapy is called portal imaging (Langmack, 2001) [1]. Portal imaging in radiation therapy is implied to attain

the main goal of radiation therapy, which is the delivery of a high conformal radiation dose to the target while sparing the surrounding normal tissue. Although, rigorous patient positioning is followed, with the advancement of collimation and treatment planning systems, uncertainties of exact tumor location are an issue since most treatments take several fractions to complete. The initial and main general objective of portal imaging is geometrical verification of treatment setup or localization to avoid errors and have better accuracy. Localization imaging could be performed before or after treatment, and a small portion of the total dose can be used for the imaging (Antonuk, 2002) [2].

Portal imaging has evolved from the tedious and time-consuming film method to a more convenient and easier aSi EPID (amorphous silicon electronic portal imaging device) method. Currently aSi is the standard, with its better image quality in comparison to the other EPIDs (Matsumoto et al., 2012) [3]. Anatomical landmarks and field borders from reference simulation or DRR (digitally reconstructed radiographs) images are compared with portal images for verification of patient setup and adjustment of patient positioning in accordance with the radiation field.

Quality control assessment of EPID is a necessary task to perform before any portal dosimetric measurements to make sure its reliable performance. A quality control phantom from PTW and its accompanying software called epidSoft are used for the quality control tests, which include mechanical integrity and proper functionality of the EPID.

EPIDs features such as having good spatial resolution and linear response to radiation dose exposure made them a good contender for dosimetric purposes. Apart from image calibration of the portal imager performed to eliminate the nose and to have spatially uniform image, dosimetric calibration of the EPID is necessary before any dosimetric measurement, for relating the delivered dose with the corresponding EPID signal. The conversion of measured field pixel values to observed dose is using a calibration factor (CF) (Tyler et al., 2013) [4]. VMAT (Volumetric Arc Radiotherapy) plans, which are complicated and personalized employ high conformal dose for treatment. QA

of each such plans for a patient is a protocol (Bailey et al., 2011) [5]. In this study, external software for pretreatment portal dosimetry called EPIQA is configured to be used with the Truebeam LINAC. Its performance of plan QA is compared with portal dosimetry system from Varian medical systems for 6MV beam VMAT plans, although both have a different approach of configuration and calculation. Also, QA of 6MV FFF beam plans are demonstrated and analyzed with the Truebeam capability of delivering 6MV FFF and 10MV FFF beams and EPIQAs added feature of pretreatment QA analysis of FFF beam plans.

II. MATERIALS AND METHODS

In the study, the TrueBeam LINAC and the integrated MV-imaging unit (aS1000 EPID) (from Varian medical systems, Palo Alto California, USA) are used for the measurements performed. The LINAC is one of the most advanced system available because of its several ranges of capabilities; including integrated imaging, treatment delivery; real-time treatment tracking and respiratory gating.

The aS1000 EPID detector system is mounted on the robotic support arm called E-arm, which is used for placing the detector to an accurate and reproducible working position, perpendicular to the treatment gantry head. The E arm allows the detector to be positioned at 95 to 180 cm from the radiation focus point (source), and the detector has a 40 x 30 cm² active imaging area with the E-arm positioning of the detector at 100 SDD (source-detector distance). The aS1000 has an active imaging area with 1024 x 768 pixel matrix. The EPID has a pixel resolution of 0.39 mm, and it is capable of capturing 14-bit images at 30 fps (frames per second) (Varian Medical Systems, 2006) [6].

Portal imaging is used for verification of treatment setup by relating portal images with relative standard reference imaging (Herman et al., 2001) [7]. There are three ways of acquiring portal images in respect to each treatment fraction, which are before treatment, during treatment and after treatment. Other than monitoring treatment session and setup, during treatment acquisition can be performed for dosimetric purposes with integrated image capture.

A. Quality Control of the EPID

Attaining consistent image quality is required with the use of EPID, so periodic QC of it must be followed. The PTW EPID quality control phantom was used in this project. The Phantom is square shaped having 25 x 25 x 4.8 cm³ dimensions and 3.8 kg weight (Das et al., 2011) [8]. Detail description on how to make a measurement with the phantom is dealt by Das et al., 2011. The PTW Quality control Phantom has five test elements incorporated in it, which are used for the regular periodic checks made. The Software named epidSoft 2.3 is used for the analysis of the measurements made with the QC phantom (PTW, 2008) [9].

Signal to noise ratio (SNR) which is the measure to define the noise signal from the acquired total signal and Signal linearity are measured with the copper step test elements in the phantom. Six brass blocks are used as test elements to determine the local dependence of linearity. An aluminum test element incorporated in the phantom, resembling the Las Vegas phantom is used for the measurement of low contrast resolution. The 14 line patterned lamella blocks with resolution between 0.167 lp/mm to 3.5 lp/mm in the upper part of the phantom are the test elements to determine the modulation transfer function (high contrast resolution) (Das et al., 2011) [10].

B. Image Calibration of the EPID

Image calibration of the detector involves removal of image background noise (dark field image), correction of detector pixel sensitivity (flood field image) and defective pixel correction. The regular periodic imager calibration is performed, so to have a uniform spatial response from the detector field. Image calibration is performed for all possible energy and dose rate combinations used for image acquisitions to consider all possible detector responses. The background noise should be corrected preferably before every measurement but the pixel sensitivity of the detector, which is corrected by flood field image acquisition, tends to have minimal variation in a month period (Menon and Sloboda, 2004) [11].

C. Portal dosimetry

Profile correction is a necessary task for dosimetric purposes. Profile correction eliminates 5% dosimetric inaccuracy that could arise because of the beam off-axis ratio (Adestam, 2003) [12]. The Varian treatment planning (Eclipse version 11) integrated portal dosimetry uses portal dose image prediction (PDIP) algorithm to attain the theoretical expected measure of all the treatment fields. A verification QA is performed by comparing the actual portal dosimetric measure and the predicted portal dose fluence. The predicted portal dose image is for 2D pretreatment evaluation, and it does not account patient and the treatment table. Further, since currently Varian portal dosimetry does not support the flattening filter free (FFF) beams, treatment plans with FFF beams are to be verified with external software called EPIQA. The software is used for pretreatment non-transit dosimetric and routine machine QA purposes (EPIQA, 2013) [13]. The software uses an algorithm called GLAAs for transforming the integrated image acquired for dosimetric verification purposes to dose map for comparison with the dose map exported from the TPS. A detailed description of the algorithm called GLAaS is given by (Nicolini et al., 2006) [14].

Portal integrated imaging is used for dosimetric measurement purposes or sophisticated treatment plan QAs because the method employs the total prescribed dose for

imaging. Five VMAT plans with 6 MV beam in total having ten arc fields were analyzed using both Eclipse integrated portal dosimetry and external EPIQA software. Non-transmission 2D portal VMAT plan QA performance of both systems are evaluated and compared since they have a different approach to configuration and calculation. Also, four VMAT plans with 6MV FFF beam, in total having nine arc fields were analyzed using EPIQA to demonstrate the EPIQAs capability of pretreatment 2D QA analysis of FFF beams. 6MV FFF beam plan measurement were setup at an extended SDD (source detector distance) of 150cm while for measurement of 6MV plans the standard 100 SDD is used. The reason for using longer SDD for FFF beams is to avoid detector saturation.

III. RESULTS

a. Quality Control of the EPID

The captured single frame QC images of the PTW phantom is saved in Dicom format for analysis use by epidSoft 2.3 software version. The earlier 2.0 version were not able to recognize Dicom format as reported by Pesznyak C, et al. 2009 [15]. The software automatically selects ROI (region of interest) after proper positional calibration to avoid the prevalence of an edge effect on the analysis result. The epidSoft software shows analysis pass and fails based on the user defined range of acceptance. The Figures 1-3 show the analysis plots from epidSoft for PTW QC image acquired with 6MV beam and 3MU dose.

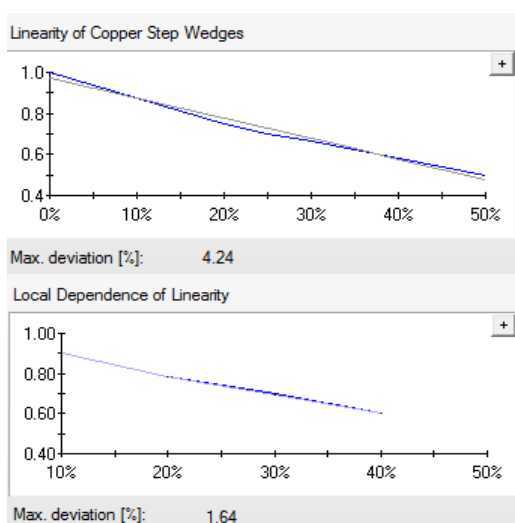


Fig. The linear plot of the copper step wedges showing 4.24% maximum deviation from the regression line (left) and The local dependency of linearity plot showing a maximum deviation of 1.5% from the linear regression (right). For both analysis measures, a maximum deviation of 5% was set as a tolerance.

The Low contrast resolution analysis is presented in numerical and interactive 3D bar graph format, representing the bore holes arrangement in the phantom. For 0.5 contrast difference selection between the holes and their surroundings, the test measurements passed as demonstrated in the figure below.

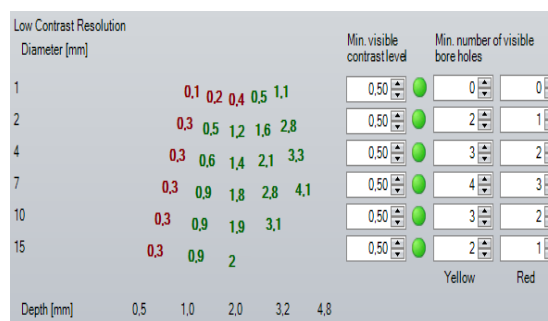


Fig. 2 The Low contrast analysis is depicted above showing 3D plot on the left and numeric representation on the right.

The EPID performance is further evaluated for SNR (signal to noise ratio) and MTF (modulation transfer function) with their assigned test elements in PTW QC phantom. MTF is used for the determination of high contrast resolution of the EPID. The horizontal and vertical MTF analyses were 0.678lp/mm and 0.782lp/mm respectively, which can be used as a baseline for future EPID performance.

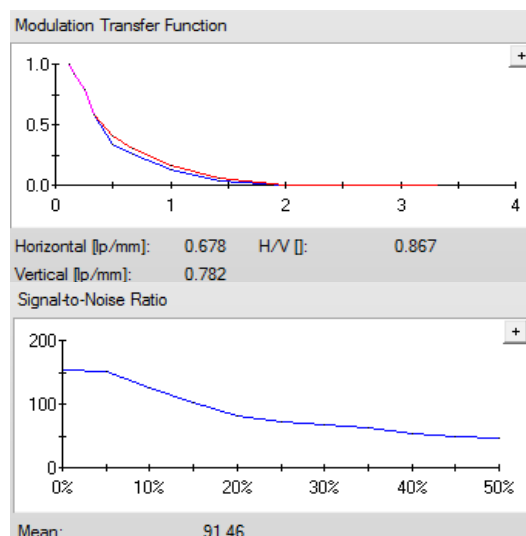


Fig. 3 Modulation transfer function (MTF) plot for all the orientations studied (horizontal and vertical) and Signal to noise ratio (SNR) plot, having a mean value of 91.46 with lower limit tolerance set to be 50.

PTW QC evaluations of the EPID with epidSoft could be saved and recalled making it possible for statistical comparison and monitoring of the degradation of the detectors over a specified period. As reported by (Das et al.,

2011) [16] the analysis follow-up of aS1000 for a month have not shown a significant verification.

b. Image Calibration of the EPID

Image calibrations were performed immediately before any measurement for the most part while carrying out the project. It should be noted that the image calibration task of flood field must be performed at the desired SDD of imaging per beam type. Although, the default SDD for imaging is 100cm, to avoid detector saturation with the use of FFF beams 150cm distance is used, which means the calibration should also be at the defined distance.

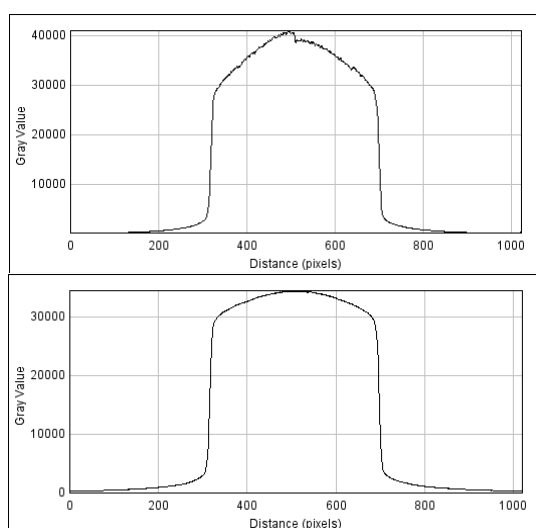


Fig. 4 Horizontal profile plot of 10 x 10 portal dosimetric field acquired with 6MV FFF beam having 50MU dose. The left one show how the profile appears before any Image calibration and the profile to the right is after proper dark field and flood field image calibration of the portal imager for FFF beam.

c. Portal dosimetry

Pretreatment 2D portal dosimetry for QA of 5 VMAT treatment plans was performed. The two separate methods from Varian and EPIQA for pretreatment portal 2D QA were evaluated and compared. The tables below depict the results from the analysis measurements of the two separate methods.

Table 1. The gamma analysis (3%, 3mm) made for the evaluation of 5 test VMAT patient plans with external software EPIQA. Each plan has two arc fields, and the table above shows the average analysis values of each arc per plan. Each Arc field evaluation passed the tolerance gamma of 95% since for whole plan to pass each arc field should pass.

6MV FF beam plans (EPIQA)	Gamma index (3%,3mm)	Mean deviation	Maximum deviation	Standard deviation	Median
1	99.33	0.24	1.70	0.21	0.17

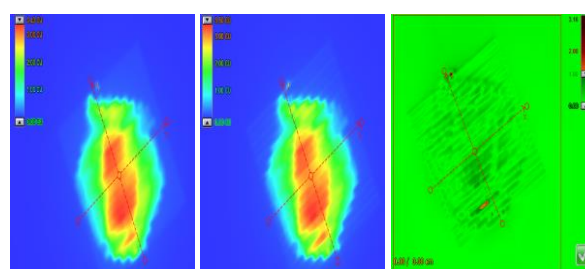
2	99.62	0.22	3.22	0.19	0.16
3	99.62	0.19	2.05	0.16	0.15
4	99.58	0.19	1.91	0.17	0.14
5	99.29	0.22	1.76	0.21	0.18

Table 2. The gamma analysis (3%, 3mm) made for the evaluation of 5 test VMAT patient plans with treatment plan incorporated Varian portal dosimetry. Each plan has two arc fields and the table above shows the average analysis values of each arc per plan. Each Arc field evaluation passed the tolerance gamma of 95% since for whole plan to pass each arc field should pass.

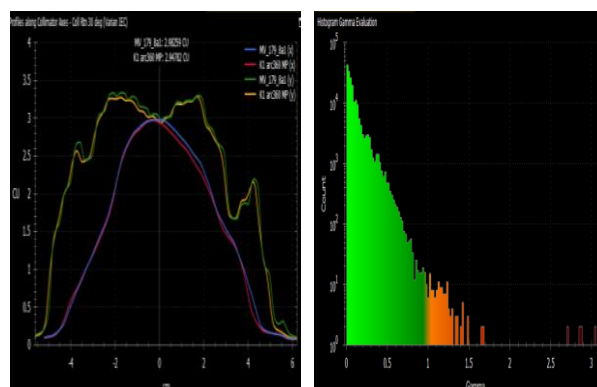
6MV FF beam plans (Varian)	Gamma index (3%, 3mm)	Mean deviation	Maximum deviation	Maximum dose difference (CU)	Mean dose difference (CU)
1	99.7	3.12	0.18	0.49	0.02
2	99.3	3.33	0.19	0.61	0.02
3	99.9	1.9	0.15	0.48	0.02
4	99.9	3.06	0.12	0.89	0.03
5	99.5	2.12	0.19	0.41	0.02

It was evident that the two separate methods had very close analysis results for the chosen treatment plans. Although, since the Varian method is incorporated into the treatment planning system (Eclipse ARIA 11) it was faster to perform the test. Both systems could easily be implemented for a radiotherapy department to have a fast and reliable evaluation of pretreatment plans.

One test plan field of a prostate tumor patient with 6 MV beam energy and 500 MU/min is selected here to show how Varian portal dosimetry appears.



Predicted image Measured image Gamma analysis



Profile plot Histogram

Fig.5. The predicted, the measured, and the gamma analysis are shown from left to right consecutively for one selected field. 99.9% of the field passed the gamma analysis based on the tolerance as shown in the gamma

analysis figure at the middle. Also, the profile agreement between the two compared dose maps of both axes (x and y respectively from the left side) and gamma evaluation histogram plot on the (right most side).

It was possible to perform and demonstrate the portal pretreatment plan QA for 6MV FFF beam plans after the proper configuration of the EPIQA system. The table below shows the analysis made for four such plans and it was evident that the EPIQA supports such task, unlike the Varian portal dosimetry.

Table 3. The gamma analysis (3%, 3mm) made for the evaluation of 4 test VMAT patient plans with EPIQA. Each plan has two-three arc fields, and the table above shows the average analysis values of each arc per plan. Each Arc field evaluation passed the tolerance gamma of 95% since for whole plan to pass each arc field should pass.

6MV FFF beam plans (EPIQA)	Gamma index(3%, 3mm)	Mean deviation	Maximum deviation	Standard deviation	Median
1	99.56	0.29	2	0.23	0.22
2	97.2	0.33	1.55	0.28	0.20
3	98.61	0.30	1.46	0.24	0.25
4	97.94	0.31	1.86	0.23	0.25

One test plan arc field of a lung patient with 6MV FFF beam energy and 14000MU/min dose rate is selected here to show how the image representation for the EPIQA evaluation analysis appears.

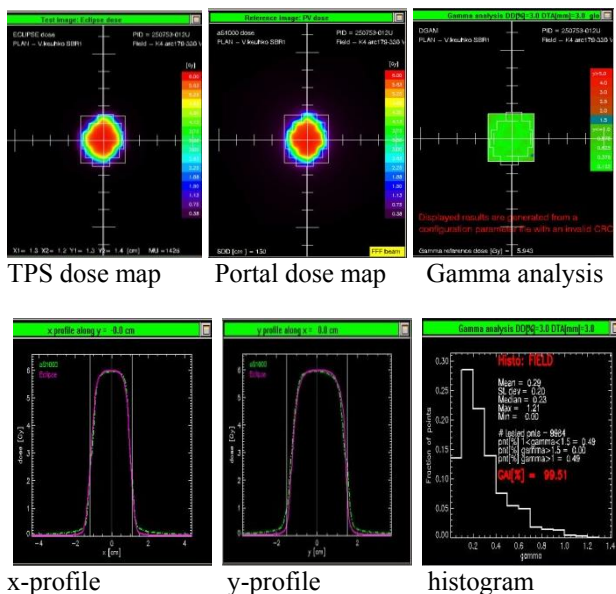


Fig. 6 Gamma analysis and comparison between TPS dose map and the EPIQA converted portal dose map. The Gamma analysis with 3% and 3mm for the first arc passed with 99.51%, which means the gamma index value evaluated was below or equal to 1 for 99.51% of the field under study. Also, the profile agreement between the two compared dose maps of both axes (x and y respectively from the left side) and gamma evaluation histogram plot on the (right most side).

It should be noted that if any one of the evaluated fields fails the gamma evaluation with the set criteria the whole dosimetric QA fails. The rule is valid for both evaluations made with EPIQA and Varian portal dosimetry.

IV. DISCUSSION AND CONCLUSION

EPID development came a long way to the current aSi EPID, which attains better image contrast and resolution in comparison to the other successfully commercialized EPIDs. Periodic quality control monitoring of the EPID performance is an important task. Based on the suggestions from (Herman et al., 2001) [17] daily, monthly, and annual QC checks of different caliber are in order. The PTW QC phantom has several test elements for evaluation of the monthly image quality tests of the EPID. One of the image tests included is MTF, which is used for determining high contrast resolution of the imager. However, since we are using a detector with an already known pixel resolution of 0.39 mm, the MTF evaluation may not be significantly needed. The QC analysis with the use of epidSoft software is not automated, since it involves exporting and importing images after the measurements.

Measurement with the EPID should be strictly confined to the active imaging area to avoid undesired radiation exposure to the surrounding sensitive electronics. As known for a few years that the EPID could potentially be used for dosimetric, and routine machine QA purposes other than patient setup verification, which is its intended initial purpose. With the prevalence of IMRT, VMAT and Rapidarc treatments, which use complicated planning for accurate conformal dose delivery, pretreatment dosimetric QA is a good practice. The accuracy of a treatment dose calculation, precise treatment location, and proper treatment machine functionality are part of the QA test.

In most radiotherapy departments, films and ion chambers are used for 2d dosimetry verifications. However, the EPIDs are also suitable, faster and easier to use for such purposes. Even for in vivo point dose measurements, EPIDs could also be used with an incorporation of complicated back projecting algorithms to give 2d dosimetric data.

The Portal imagers (aS1000) working field size limits measurement of larger field size plans, the issue is more prevalent when measuring at longer SSD than 100cm. For example, FFF beams portal measurement, which requires 150cm SSD to eliminate saturation of the detector.

The portal imager characteristics, which made it appealing for dosimetric purposes are its dosimetric linear response, that it gives reproducible dosimetric response (Green and Vail, 2011) [18] and its negligible memory or ghosting effect of the detector for simultaneous measurements (Greer and Popescu, 2003) [19].

Varian medical systems recently introduced aS1200 EPID to address the measurements issues with aS1000 EPID. The new EPID system integrates a metal plate between the detector and the support arm to remove the

backscatter effect and has larger detector active area of 43 x 43 cm² with 1280 x 1280 pixel matrix to support larger field size plan measurements (Varian medical system, 2013) [20].

Pretreatment QA methods from both EPIQA and Varian for 6MV beams are comparative and reliable. The QA evaluations determined the project aim to be correct. Since the measurement results were under acceptable tolerance. Also, EPIQA system showed that it supports pretreatment FFF beam plan QA, which is not currently supported by the Varian portal dosimetry system.

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