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Original paper

Comparison of two different EPID-based solutions performing pretreatment quality assurance: 2D portal dosimetry versus 3D forward projection method

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ABSTRACT

Purpose: The aim of this paper is to characterize two different EPID-based solutions for pre-treatment VMAT quality assurance, the 2D portal dosimetry and the 3D projection technique. Their ability to catch the main critical delivery errors was studied.

Methods: Measurements were performed with a linac accelerator equipped with EPID aSi1000, Portal Dose Image Prediction (PDIP), and PerFRACTION softwares. Their performances were studied simulating perturbations of a reference plan through systematic variations in dose values and micromultileaf collimator position. The performance of PDIP, based on 2D forward method, was evaluated calculating gamma passing rate (%GP) between no-error and error-simulated measurements. The impact of errors with PerFRACTION, based on 3D projection technique, was analyzed by calculating the difference between reference and perturbed DVH (%ΔD). Subsequently pre-treatment verification with PerFRACTION was done for 27 patients of different pathologies.

Results: The sensitivity of PerFRACTION was slightly higher than sensitivity of PDIP, reaching a maximum of 0.9. Specificity was 1 for PerFRACTION and 0.6 for PDIP. The analysis of patients' DVHs indicated that the mean %ΔD was (1.2 ± 1.9)% for D2%, (0.6 ± 1.7)% for D95% and (−0.0 ± 1.2)% for Dmean of PTV. Regarding OARs, we observed important discrepancies on DVH but that the higher dose variations were in low dose area (< 10 Gy).

Conclusions: This study supports the introduction of the new 3D forward projection method for pretreatment QA raising the claim that the visualization of the delivered dose distribution on patient anatomy has major advantages over traditional portal dosimetry QA systems.

1. Introduction

Electronic Portal Imager Devices (EPIDs) have been developed for acquiring megavoltage digital 2D images during treatment for patients' position verification. However, the large detection surfaces, the good linear response to radiation dose, and the online dosimetric responses make EPIDs useful candidates for intensity modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT) patient-specific pre-treatment quality assurance (QA) [1–3] and in vivo dosimetry [4].

Nevertheless, EPIDs are not made out of water-equivalent material but they are composed of high-Z materials [5,6]. Consequently, algorithms have been developed to convert the measured portal image to dose distribution in water and, subsequently, to compare it to the dose calculated by the Treatment Planning System (TPS) in a water-equivalent phantom, or to predict calibrated EPID response using the fluence data of patients plan and to compare it with measured portal dose images [6,7]. In addition to these algorithms, known as forward/transit methods or portal dosimetry, researches have explored another method, called backward method or in vivo dosimetry, based on the calculation of the 3D patient dose distribution on CT scans from EPID information through a back-projection approach [8,9].

The inconveniences of the forward method are related to the efforts in EPID calibration and corrections and to the complexity of understanding how differences in dose at the EPID plane are related to differences in dose to the patient, while the inconveniences of the second method are the inaccuracies of algorithms in backprojecting doses on patient CT and the difficulty in understanding the source of errors on the 3D dose deposited in the patient.

In a first step of this study we evaluated the sensitivity of EPID alone, independently on any software-based post-processing, by

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simulating errors and delivering them on a phantom. A second step of this work regarded the comparison of the portal dose image prediction-PDIP algorithm (Varian Medical System, Palo Alto, CA, USA) and the PerFRACTION software (Sun Nuclear Corporation, Melbourne, FL, USA) through their pre-treatment results.

PDIP is based on forward method and results are in terms of gamma metric, while PerFRACTION is based on a modified in vivo method, characterized by an intermediate solution between transit and backward approach, known as 3D forward projection technique, and provides a DVH-based metric.

As well described by Van Esch [10], the PDIP algorithm leaves measurements untouched, but it uses a separate beam model, instead of the dose calculation algorithm implemented in TPS, to compute the expected portal dose image based on the theoretical TPS photon intensity matrix, the main collimator positions, and the total monitor units (MUs) [11,12]. Instead, the PerFRACTION performs a pre-treatment phantom free IMRT/VMAT QA through a dose reconstruction on patient CT based on the information concerning the multi leaf collimator (MLC) and collimator positions obtained by analyzing the EPID images with a propriety edge detection algorithm and on the information available into the machine log files, such as the MUs and the gantry angles [13]. A convolution/superposition algorithm is used to calculate the dose distribution from this information on plan CT (for pre-treatment QA) and on CBCT (for daily online treatment check purpose).

The aim of this study is to analyze the different commissioning and calculation approaches of the two systems and to test their ability to catch the main critical delivery dose errors in pre-treatment QA, after having established the intrinsic sensitivity of EPID.

Subsequently a pre-treatment verification with PerFRACTION was done for 27 patients with different pathologies. This analysis was performed on PTVs and some OARs of the treated anatomical district.

2. Materials and methods

All EPID images were acquired with an amorphous silicon (aSi) flat panel (aS1000) irradiated with a linear accelerator TrueBeam STx (Varian, Palo Alto, CA) using a 6 MV photon beam. The TrueBeam STx is equipped with a 120 HD micro MLC. All dose distributions were calculated by using the Analytical Anisotropic Algorithm (AAA) algorithm implemented in the Eclipse TPS (Varian, Palo Alto, CA). The sensitive area of the imager is $40 \times 30\,cm^2$ (1024×768 pixels), consequently the size of each pixel is $0.39 \times 0.39\,mm^2$ at the detector surface. The maximum frame acquisition rate is 30 frames/second, the energy range is 4–25 MV and the permitted dose rates are 50–600 MU/min. This model of EPID does not allow measurements with flattening filter free beam.

The Varian electronic image acquisition software provides both integrated and cinematic modes for portal dosimetry acquisition. During the radiation delivery, the image is acquired in integrated mode for PDIP dosimetry, instead for PerFRACTION dosimetry the image is acquired in cinematic mode (each individual frame is recorded over the entire beam-on time).

The implementation of the two different EPID-based systems consisted of a flat panel calibration for the forward method and of a configuration and validation of the dedicated algorithm for PerFRACTION.

2.1. PDIP algorithm implementation

The PDIP algorithm calculates predicted portal dose images from IMRT or VMAT plans and then compares them to the EPID measured images, at the level of EPID, for pre-treatment plan verifications. Detailed explanation on how the PDIP algorithm works are available in the literature [11].

The configuration of the PDIP algorithm requires: diagonal profile correction, output factor measurements, the beam intensity profile and a pyramid-shaped test image.

Before PDIP configuration, dark field (DF) and flood field (FF) were required for offset and gain corrections of each pixel. Nevertheless, the FF correction is not sufficient for dosimetric acquisition purpose as it results in a flat dosimetric image of a $40 \times 30\,cm^2$ open field, even in the penumbra region. Since the FF calibration does not take into account off-axis variations of the beam, assuming beam intensity as radially symmetrical around the central axis, a correction for beam profile shape is needed. The official procedures suggest to use a beam diagonal profile of a $40 \times 40\,cm^2$ field measured in a water phantom at the depth of the maximum dose (d_{max}).

Finally, output factors were acquired with the EPID at the isocenter for field sizes ranging from $3 \times 3\,cm^2$ to $40 \times 30\,cm^2$ and a pyramid-shaped test image is used by the algorithm to derive the pencil beam kernel which describes the photon scatter within the detector.

2.2. Optimization of EPID calibration for PDIP

Portal dose distributions of nine fields ($3 \times 3\,cm^2$, $5 \times 5\,cm^2$, $10 \times 10\,cm^2$, $15 \times 15\,cm^2$, $10 \times 20\,cm^2$, $20 \times 10\,cm^2$, $40 \times 5\,cm^2$, $40 \times 10\,cm^2$, $40 \times 20\,cm^2$) were acquired and compared to the predicted ones to test the accuracy of the implemented PDIP algorithm, as suggested by vendor. The acquired portal images were compared, by using %GP, with the calculated ones (used as reference). To improve the agreement between predicted and measured profiles, we tested, in addition to $d_{max,}$ other two different diagonal dose profiles relative to a $40 \times 40\,cm^2$ open field, measured at depths 50 mm (d_{50}) and 100 mm (d_{100}) respectively. We tested them to find the one which minimizes the deviations between measured and predicted doses.

The PDIP single pencil beam kernel was then fine-tuned by importing the test image with the improved profile correction into the PDIP basic beam data and rerunning the algorithm configuration.

The same nine fields were used to verify the corrections of the new applied profile.

2.3. PerFRACTION implementation

The dose calculation algorithm in PerFRACTION is an independent, GPU-accelerated convolution/superposition algorithm, named Sun Nuclear Dose Calculator (SDC) [14,15]. PerFRACTION uses the SNC Dose Calculator for pre-treatment QA and in vivo QA but it also uses the SDC to produce an entire dose volume to check against that from the Treatment Planning System (TPS).

Furthermore, PerFRACTION allows the possibility to use SDC algorithm as reference instead of the TPS algorithm eliminating the potential differences stemming from the use of different calculation algorithms, due to algorithm itself as well as secondary factors such as dose grid size, ROI segmentation and calculation of DVH. PerFRACTION does not need a commissioning since a beam model for each linear accelerator, MLC, and beam energy combination is provided by Sun Nuclear Corporation. The user has to supply the local CT number-to-ED conversion table and the absolute output per monitor unit under the reference conditions

The SDC beam model is created by Sun Nuclear Corporation following a two-step process: percent depth dose, profiles, and output factor data are based on average measurements for five machines of the same class

Then, IMRT and VMAT patient plans are evaluated to ensure proper MLC parameters are in place, including leaf thickness and density, leaf curvature and offset position, and tongue-and groove thickness.

We selected and validated the proposed beam model by calculating the dose discrepancies between our reference TPS calculation algorithm (AAA) and SDC algorithm, for a standard VMAT plan on solid water phantom and on 30 patients' plans with different inhomogeneities. We recalculate the dose distribution using the same DICOM RT Plan exported from treatment planning system. Percentage dose difference at the isocenter and 3D gamma analysis with 2%/2 mm criterion were