Original Article

Simple Electronic Portal Imager-Based Pretreatment Quality Assurance using Acuros XB: A Feasibility Study

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Abstract

Objective: This study demonstrates a novel electronic portal imaging device (EPID)-based forward dosimetry approach for pretreatment quality assurance aided by a treatment planning system (TPS). **Materials and Methods:** Dynamic multileaf collimator intensity-modulated radiation therapy (IMRT) plans were delivered in EPID and fluence was captured on a beam-by-beam basis (F_{EPID}). An open field having dimensions equal to those of the largest IMRT field was used in the TPS to obtain the transmitted fluence. This represented the patient-specific heterogeneity correction (F_{het}). To obtain the resultant heterogeneity-corrected fluence, EPID measured fluence was corrected for the TPS generated heterogeneity ($F_{Resultant} = F_{EPID} \times F_{het}$). Next, the calculated fluence per beam basis was collected from TPS (F_{TPS}). Finally, $F_{Resultant}$ and F_{TPS} were compared using a 3% percentage dose difference (% DD)-3 mm distance to agreement [DTA] gamma analysis in an isocentric plane (two-dimensional [2D]) and multiple planes (quasi three-dimensional [3D]) orthogonal to the beam axis. **Results:** The 2D heterogeneity-corrected dose reconstruction revealed a mean γ passing of the pelvis, thorax, and head-and-neck cases of 96.3% ±2.0%, 96.3% ±1.8%, and 96.1% ±2.2%, respectively. Quasi-3D γ passing for the pelvis, thorax, and head-and-neck cases were 97.5% ±1.4%, 96.3% ±2.4%, and 97.5% ±1.0%, respectively. **Conclusion:** EPID dosimetry produced an inferior result due to no heterogeneity corrections for sites such as the lung and esophagus. Incorporating TPS-based heterogeneity correction improved the EPID dosimetry result for those sites with large heterogeneity.

Keywords: Electronic portal imaging device, portal dosimetry, pretreatment quality assurance

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Introduction

Intensity-modulated radiation therapy (IMRT) is widely used in radical treatments and is presently considered to be the standard of care for major treatment sites. The complexity of dose planning and delivery makes it essential to implement stringent quality assurance (QA) for IMRT. Dose verification can be performed either as pretreatment verification or during therapy delivery (*in vivo*). Pretreatment verification requires monitor unit (MU) verification and fluence measurements using either an ion chamber array, film, or portal imager (electronic portal imaging device [EPID]).[1,2]

Several other methodologies are available to determine the absolute dose at specific points, which is usually performed using ionization chamber measurements. The relative dose distributions can be verified by film measurements, ionization chamber arrays, diode arrays, or gel dosimetry in three dimensions.[1,3,4] These patient-specific QA methodologies are time-consuming and sometimes yield only limited information. The easiest method of verifying a patient-specific treatment plan necessitates the use of a portal imaging device, which requires the activation of the imager panel. EPID is a reliable dose verification system when considering the directional dependency of the beam-limiting devices and the imager panel systematic shifts and tilts.[2,5] There are two EPID dosimetry methods and both are suitable for *in vivo* dosimetry and pretreatment verification. The first method is based on the back-projection approach, where the dose fluence at EPID level is measured in the absence (free air or phantom measurement) or presence (transit dosimetry) of the patient. The collected

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EPID fluence is back-projected and reconstructed in the patient or in a phantom.[6-10] The second method is the forward approach, where the measured dose in the portal imager plane is compared to the treatment planning system (TPS) predicted dose or photon fluence.[11,12] The back-projection approach was efficiently used by several investigators, including groups from the Netherlands Cancer Institute (AVL-NKI), who successfully performed three-dimensional (3D) dose reconstruction using a back-projection algorithm.[7-10,13] They were able to further automate EPID dosimetry for all types of treatment fields.[14] AVL-NKI reported good conformity among the studied cases without requiring significant heterogeneity corrections. Among all of their published reports, the AVL-NKI group failed to achieve good agreement between the measured and calculated fluence/dose for sites with large heterogeneities, such as the lung and esophagus.[14,15] In some cases, the investigators are still considering the lung, esophagus, and some breast cases without heterogeneity correction while calculating the dose in the TPS for 3D EPID dose reconstruction.[14] This discrepancy is attributed to two factors. First, the air/phantom-based EPID measurement does not account for the patients' heterogeneity, which is an inherent drawback in EPID dosimetry. Second, a difference exists in the dose calculation algorithms used in the TPS and the back-projection technique. In their earlier report, the AVL-NKI group claimed that a back-projection algorithm should independently verify the treatment planning, and its accuracy does not need to be as high as that of the TPS.[7] We agree with the first point but not with the second. The planning system has devolved significantly over the last few decades from a pencil beam to a Monte Carlo dose for dose calculation. Nevertheless, the back-projection algorithm has not developed in parallel with the TPS algorithm. Therefore, the back-projection algorithm is unable to fulfil the desired accuracy for the inhomogeneous site. However, the forward EPID dosimetry approach using Monte Carlo simulation was described by Siebers *et al.* and Parent *et al.* in terms of a through-air portal dose image for Varian and Elekta EPID systems, respectively. Their approach yields useful information for patient-specific QA; however, it may be difficult to apply in routine clinical practice.[16,17] Although a significant amount of work has been conducted so far for EPID dosimetry, heterogeneity correction cannot yet be addressed effectively. The present study offers a novel methodology for EPID dosimetry, designed using a hybrid approach where in the planning system is used to calculate the heterogeneity correction, which was further multiplied by the EPID-measured fluence to obtain the heterogeneity-corrected fluence pattern. This method offers a more effective heterogeneity correction than any of the presently available techniques. We describe pretreatment verification without the patient using the same TPS algorithm utilized for patient planning to reconstruct the two-dimensional (2D) or quasi-3D dose by applying a TPS-based heterogeneity correction. The reconstructed 2D/quasi-3D dose was compared against the TPS-calculated dose distribution. As it is not exactly a 3D volume dose reconstruction, we describe this technique as "quasi-3D."

Materials and Methods

Characteristic of amorphous silicon-based electronic portal imaging device

All portal images were acquired with an amorphous silicon (aSi)-1000 aSI EPID (Varian Medical Systems, Palo Alto, CA, USA) which is attached with a Varian True Beam linear accelerator (Varian Medical Systems, Palo Alto, CA, USA) equipped with a 60-pair dynamic multileaf collimator. The EPID system includes an image detection unit containing an imager and its associated electronics. The imager dimensions are 30 cm × 40 cm with 768 × 1024-pixel resolution, leading to a pixel dimension of approximately 400 μm. Each pixel consists of a light-sensitive photodiode and a thin-film transistor for electronic readout. Accumulated charge in the photodiode was further digitized with an analog-to-digital converter. The manufacturer placed a layer of scintillating gadolinium oxysulfide above the imager and a 1-mm copper plate creates an 8-mm water equivalent depth in front of the photodiodes. Frames were acquired continuously during beam delivery. Image acquisition was interrupted after summation of 64 frames, which allowed the acquired frames to be transferred. However, charge accumulation in the photodiode does not get interrupted during the frame transfer, leading to accurate acquisition of the final image. After completion of beam delivery, all stored images were averaged over the acquired frames, resulting in a final grayscale image. No additional buildup material was used of the imager in this study. To check the consistency of the EPID pixel sensitivity, a manufacturer-defined calibration process was used.[18] However, calibration was only used to check for consistency and only grayscale EPID images were used for this study. All treatment plans were defined in the Varian's Eclipse version 13.6 (Varian Medical System; Palo Alto, CA) TPS.

Theory of dose reconstruction

Theory of dose reconstruction is presented in our early work.[19] We present the final form of the equation to calculate the planer fluence from EPID.

$$F_S = \int \int_{x=-\frac{X0}{2},\, y=-\frac{y0}{2}}^{x=+\frac{X0}{2},\, y=+\frac{y0}{2}} I_0\, \partial x \partial y \times T_{\partial xi \partial yj}^{Primarty} \times P_s\left(\partial x_i\, \partial y_j\right) \partial x \partial y$$

The collection of heterogeneity-corrected dose fluence is a two-step procedure. First, to obtain the contribution due to primary transmission and total scattering in the patient isocentric plane, an open-field fluence with the same dimensions as the largest IMRT fields was obtained from the TPS (F_{het}). This isocentric planar fluence contains the heterogeneity correction information. In the second step, the beam was delivered to the EPID in the absence of any scattering medium other than the EPID inherent buildup (F_{EPID}). F_{EPID} and F_{het} fluence patterns were converted into matrix form and multiplied to obtain the resultant heterogeneity-corrected fluence pattern from TPS ($F_{Resultant} = F_{EPID} \times F_{het}$). $F_{Resultant}$ is equal to F_s in Equation (iii). The planar fluence of the actual IMRT beam in a patient (F_{TPS}) was obtained at the isocentric

plane, and gamma matching was conducted between $F_{Resultant}$ and $F_{TPS.}$

Quasi-3D verification requires the use of F_{het} multiple planes orthogonal to the beam axis; therefore, F_{het} was normalized by the calculated MU and dimensionally adjusted as per the distance from the isocentric plane.

Pretreatment verification

Pretreatment verification: Two-dimensional planar fluence verification

Figure 1 depicts the workflow for the pretreatment QA (PTQA) and how planar dose verification using gamma analysis was performed for 15 patients. Five patients each from three different sites were evaluated in this study; the thorax, pelvis, and head-and-neck cases were collected, comprising five beams each. The head-and-neck cases used seven field plans, leading to a verification of 25 fields for thorax and pelvis patients and 35 field plans for head-and-neck cases for gamma evaluation. Figure 2 shows the experimental setup in TPS for a lung case. F_{het} was obtained from the TPS in the patient isocentric plane for 100 MU from the IMRT field and exported as a 256 × 256 matrix. Grayscale normalization was applied to the delivered MU using OmniPro-I'mRT software (IBA Dosimetry GmbH, Schwarzenbruck, Germany).

All IMRT fields were delivered on EPID, and F_{EPID} was obtained and converted into a 256 × 256 matrix after demagnifying to the isocenter plane using Mathematica V10.0 (Wolfram, Champaign, IL, USA) and OmiPro (IBA, GmBh) IMRT software. To obtain the heterogeneity-corrected measured fluence ($F_{resultant}$), F_{EPID} and F_{het} were multiplied on a pixel by pixel basis using Mathematica V10.0 (Wolfram, Champaign, IL, USA). The planar fluence of each IMRT field (F_{TPS}: isocentric coronal plane) was analyzed using Mathematica. A 3% (3 mm) gamma evaluation was performed between the $F_{Resultant}$ and F_{TPS} using OmniPro. Figure 3a presents the gamma analysis results.

Pretreatment verification: Quasi-three-dimensional planar fluence verification

The same concept was extended to quasi-3D dose reconstruction. Patient dose planes orthogonal to the beam axis (patient coronal plane) were obtained by dividing the patient anterior-posterior depth into 1-cm thick slices. Thirty patients, with ten each from the pelvis, thorax, and head-and-neck groups, were included in this study. For the pelvis, thorax, and head-and-neck cases, 26, 28, and 19 of the most common planes (F_{TPS}) were reconstructed in their respective patients. The common planes were identified as described below. If the anterior–posterior height of the patient is divided at a 1 cm separation, it will create a different number of coronal planes for different patients. It was observed that, for pelvis cases, all patients had at least 26 planes (13 from and above isocenter and 13 below isocenter); these planes are identified as the most common planes. Similarly, for the thorax and head-and-neck cases, 28 and 19 planes are common among all the patients, respectively. These planes were numbered from the beam entry point at the patient surface to the beam exit point. Similarly,

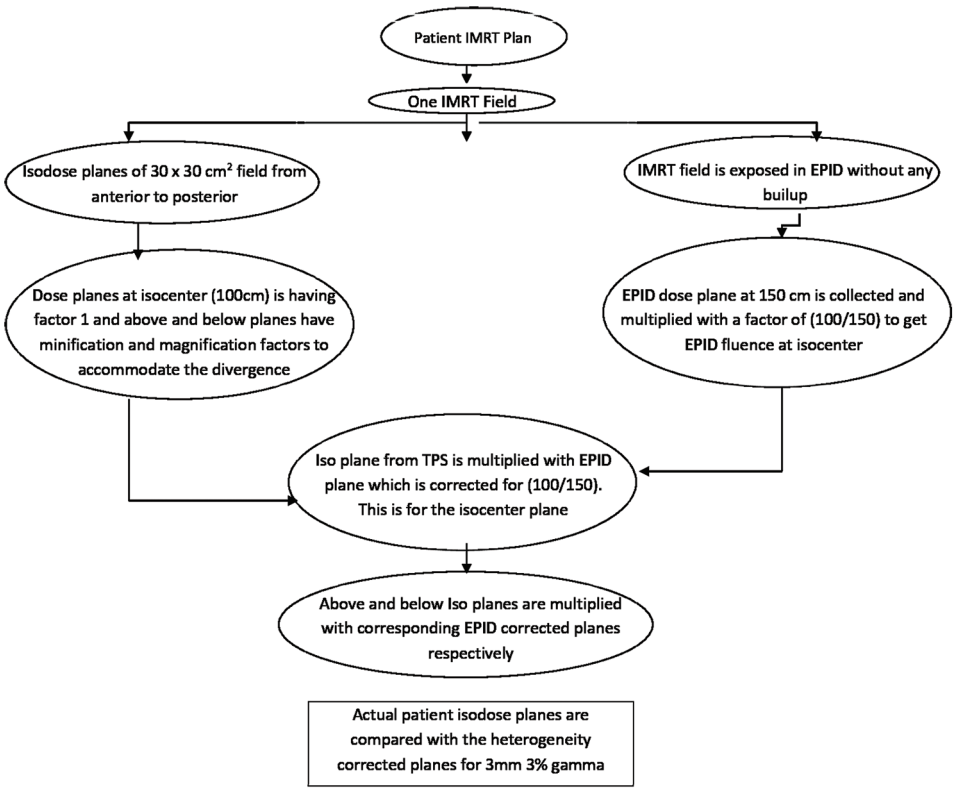

Figure 1: Workflow for pretreatment quality assurance and transit dosimetry

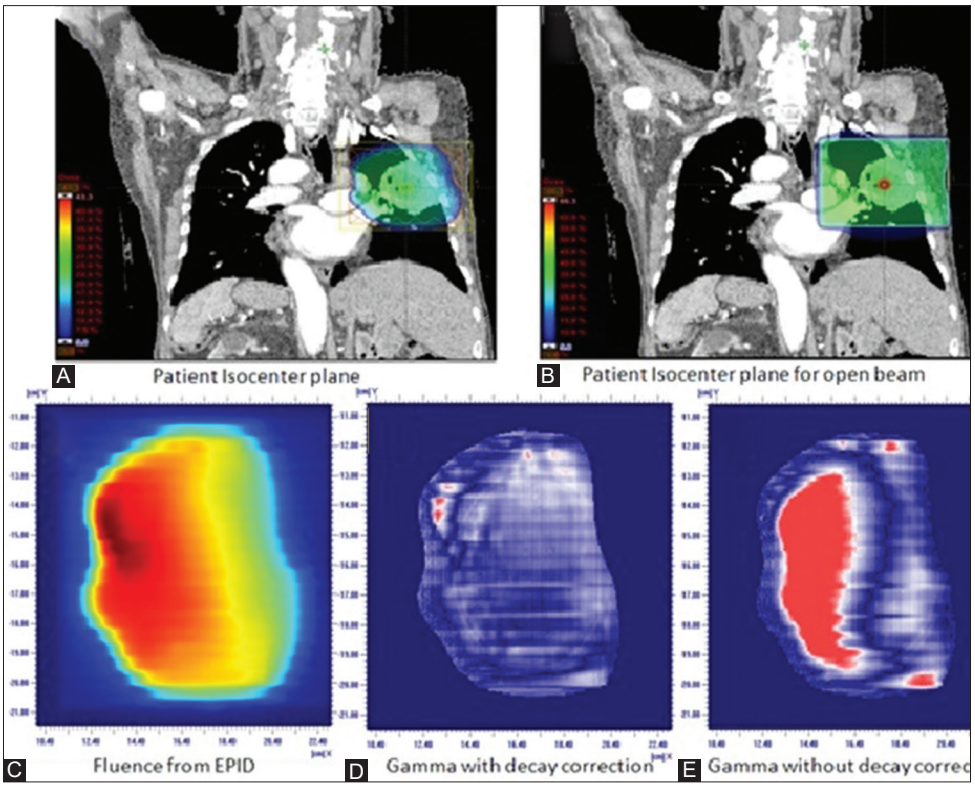

Figure 2: Represent panel A: Patient isocenter plane from treatment planning system (F_{TPS}); panel B: Open-field portal having dimension that of widest jaw position of the intensity-modulated radiation therapy field indicating the heterogeneity correction (F_{het}). Panel C: measured fluence from portal imager (F_{EPID}). Panel D: 3%-3 mm gamma-matching considering heterogeneity correction (F_{het}). Panel E: 3%-3 mm gamma-matching without considering heterogeneity correction (F_{het})

F_{het} was also obtained from the TPS. The EPID measured fluence (F_{EPID}) yields a single merged coronal plane, which was further magnified or demagnified to reconstruct the planes corresponding to the most common planes in the patient. $F_{resultant}$ was calculated for each plane corresponding to F_{het} and F_{EPID}. A 3%-3 mm gamma evaluation was performed between $F_{resultant}$ and $F_{TPS.}$ We have verified several planes per treatment plan but could not reconstruct the 3D dose volumes. Figure 3b shows the 3% DD-3 mm DTA gamma analysis results for the respective planes averaged over the number of patients.

Validation measurement

A set of verification and validation measurements for our technique are presented in the results section. In this section, we validate the EPID performance and the PTQA technique in a homogeneous phantom.

Open-beam verification (electronic portal imaging device performance testing)

To test the validity of the present concept, we performed a set of open-field measurements. Four open-field treatment plans using field sizes of 5 cm × 5 cm, 10 cm × 10 cm, 15 cm × 15 cm, and 20 cm × 20 cm were created in the patient computed tomography scan for the pelvis, thorax, and head-and-neck cases at different gantry angles. The gantry angles were G = 0°, G = 70°, G = 140°, G = 210°, and G = 280° for the pelvis and head-and-neck cases. The gantry angles in the thorax cases were G = 0°, G = 190°, G = 230°, G = 270°, and G = 310°. Dose distributions were reconstructed from the EPID images and the planned dose distributions for the IMRT fields using the 2D and 3D γ-evaluation within the 20% isodose line. Open field verification was conducted using a 50% isodose line threshold. The threshold value is used to exclude the low-dose region where the agreement within the γ-criterion is usually not acceptable.[6] F_{het} and F_{TPS} for the patient isocenter planes were transferred to the OmniPro Software. F_{EPID} was measured by exposing the beams in EPID. $F_{resultant}$ was calculated via matrix multiplication of F_{het} and $F_{EPID.}$ We also performed gamma matching between $F_{resultant}$ and $F_{TPS.}$

Pretreatment quality assurance validation

We validated PTQA as described below. A set of ten IMRT patients was considered for the validation measurements. These patients were different from the 2D or quasi-3D verified patients and already validated by a separate *in vivo* EPID transit dosimetry method. Only the fundamental principle of 2D planar fluence verification was validated, as quasi-3D dose verification is a superset of the 2D verification.

Figure 4 shows the validation scheme for the anterior beam. All the individual beams were validated in a similar manner as described in Section 2.2.1. The fluence of the isocentric

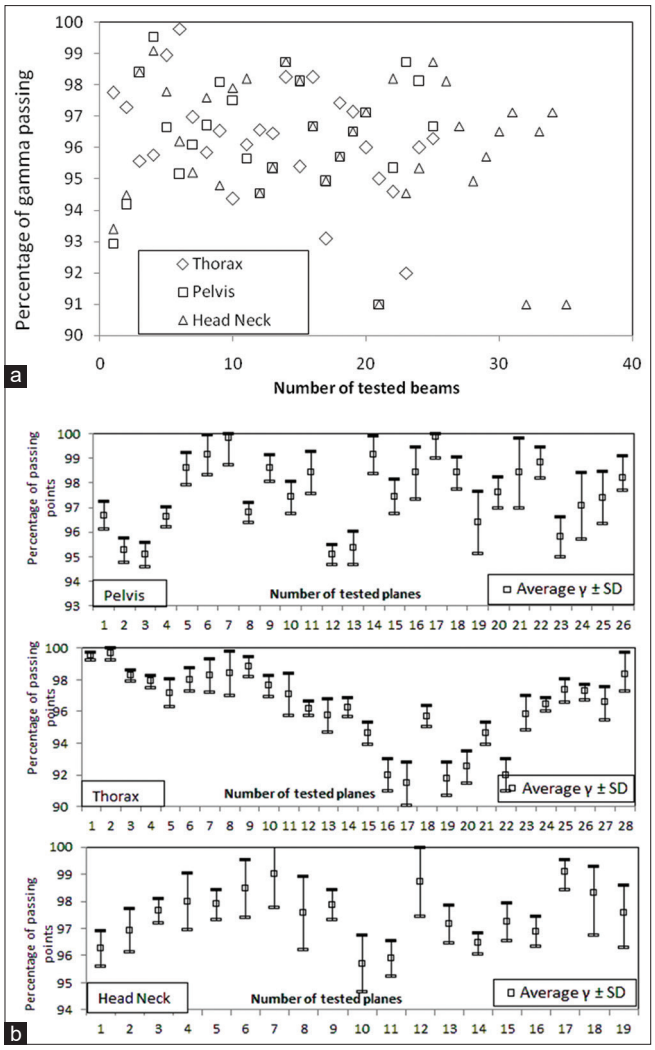

Figure 3: (a) Comparison of planning system-based heterogeneity-corrected PLANAR fluence from electronic portal imaging device in the absence of patient with the planning system calculated individual beam fluence. Gamma analysis (3% DD-3 mm DTA) results for total 85 individual beams for the thorax, pelvis and head-and-neck cases, (b) Quasi-three-dimensional dose verification using gamma analysis.

plane from the planning system was compared with the EPID measurement fluence after correcting it for the heterogeneity from an open field at the isocentric level ($F_{het—Isocentric-}$line AB in Figure 4). In the validation process, the patient exit plane was considered ($F_{het_EXIT\ Plane-}$line CD in Figure 4) instead of the patient isocentric plane. The $F_{het\_EXIT\ Plane}$ was multiplied by the EPID measured fluence in the absence of the patient (F_{EPID}). This yields the EPID fluence corrected for exit plane heterogeneity ($F_{resultant\_EXIT\ Plane} = F_{EPID} \times F_{het\_EXIT\ Plane}$). If Method 1 holds in such a case, $F_{EPID\_TRANSIT}$ should exhibit a good gamma correspondence with $F_{resultant\_EXIT\ Plane.}$

Results

Two-dimensional planar dose verification

All the plans in the pelvis and head-and-neck cases yielded a 3-mm-DTA 3% DD gamma passing of 96.3% ±2.0% and

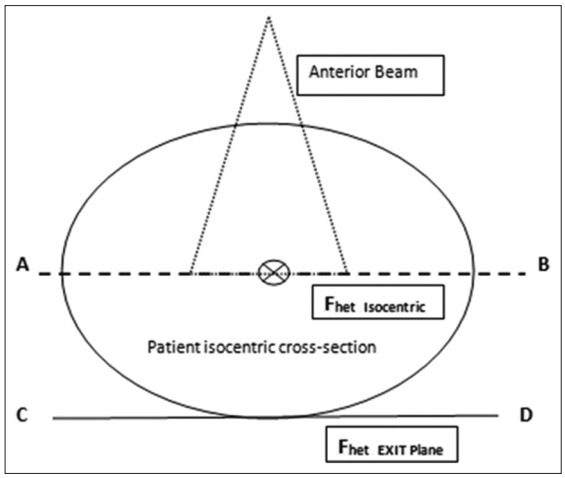

Figure 4: Validation scheme of pretreatment electronic portal imaging device verification technique using transit dosimetry result

96.1% ±2.2% points, respectively. Twenty-one out of 25 thorax beams exhibit a passing of 98.1% ±1.9%, and the four remaining fields exhibit a mean passing of 94.5% ±2.4% for the 3%-3 mm criterion. All thorax planes exhibit an overall passing of 96.3% ±1.8%.

To verify the efficacy of the heterogeneity correction in EPID-based dose verification, gamma matching was compared with the TPS values (F_{TPS}) with ($F_{EPID} \times F_{het}$) and without heterogeneity correction (F_{TPS} vs. F_{EPID}). Gamma analysis of F_{TPS} versus F_{EPID} yields a mean passing of 85.3% ±9.2%, 80.7% ±6.6%, and 80.3% ±10.9% for the pelvis, head-and-neck, and thorax cases, respectively.

The maximum and minimum gamma differences for the 3 mm-DTA 3% DD gamma analysis result were evaluated with the following methodology. The heterogeneity-corrected gamma result (F_{TPS} vs. $F_{EPID} \times F_{het}$) for a particular field was compared with its uncorrected heterogeneity (F_{TPS} vs. F_{EPID}) gamma result for each beam. The minimum gamma difference for the pelvis, head-and-neck, and thorax cases was 0.1%, 4.6%, and 0.5%, respectively, where the maximum gamma difference for the same group was 34.6%, 30.5%, and 31.3%, respectively.

Figure 2 shows a typical lung (thorax) patient for the IMRT dose distribution in the isocentric plane, F_{het}, EPID fluence, and 3%-3 mm gamma distribution with and without applying heterogeneity corrections in panels A, B, C, D, and E, respectively.

Quasi-three-dimensional dose verification

Figure 3b presents the 3%-3 mm gamma matching for the reconstructed quasi-3D volume. The mean gamma passing for the 3%-3 mm criterion incorporating the heterogeneity correction for pelvis, thorax, and head-and-neck cases was 97.5% ±1.4%, 96.3% ±2.4%, and 97.5% ±1.0%, respectively. Without applying the heterogeneity correction (not shown in Figure 3b), the mean gamma passing for the pelvis, thorax, and head-and-neck cases was 83.6% ±7.4%, 81.7% ±7.1%, and 83.0% ±7.4%, respectively.

Validation measurement and results

Open-beam verification (electronic portal imaging device performance testing) result

Open-beam gamma evaluations were tested for 5 cm × 5 cm, 10 cm × 10 cm, 15 cm × 15 cm, and 20 cm × 20 cm field sizes. Figure 5 shows the site-wise γ passing percentage for the four different field sizes. The mean gamma passing under the 3-mm-3% criterion averaged over all three sites was 95.6% ± 1.25%, 98.5% ± 0.65%, 99.0% ± 0.6%, and 99.3% ± 0.4% for the 5 cm × 5 cm, 10 cm × 10 cm, 15 cm × 15 cm, and 20 cm × 20 cm field sizes, respectively. Larger field sizes yield a higher gamma matching, which can be attributed to the elimination of low-dose signals (20%) in the analysis.

Pretreatment quality assurance validation result

Figure 6 (panels A–C) shows the validation measurement result. A comparison between $F_{resultant\_EXIT\ Plane}$ and $F_{EPID\_TRANSIT}$ shows a mean gamma (3-mm-3%) matching of 97.3% ± 1.2% averaged over 10 patients. This establishes the validation of the PTQA methodology described in this article.

Discussion

As described earlier, EPID dosimetry, especially in the back-projection technique, suffers from two drawbacks: first, EPID measurement performed in air does not account for the patient's heterogeneity, and second, the dose calculation algorithm has incompatibilities between the TPS and back-projection techniques. It is essential to incorporate the additional heterogeneity correction for the back-projection technique, especially for PTQA. Our hybrid approach for modifying the EPID measured dose using additional heterogeneity corrections from the planning system effectively addresses the heterogeneity issue**.** The rationale of using a TPS-calculated heterogeneity correction in the EPID dose verification is explained herein. The main disadvantage of presently commercially available or in-house software is the incompatibility of the algorithm with the TPS. Although planning system algorithms have devolved significantly over the last two decades, the EPID-based dose verification software still uses a pencil beam algorithm without considering tissue heterogeneity.[6,11,20]

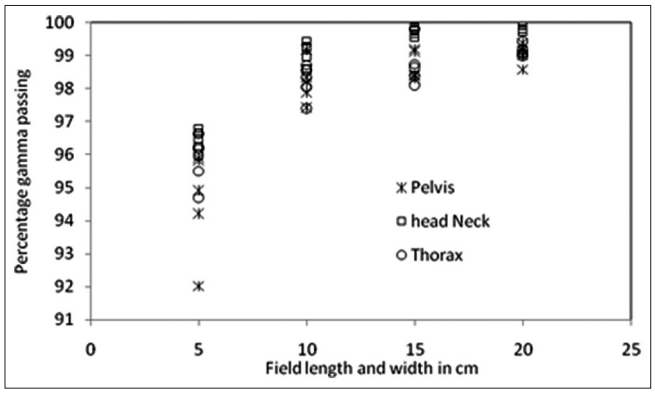

Figure 5: Open-beam measurement result for 3% DD-3 mm DTA gamma

In our technique, we did not use any dose calculation from the EPID measured fluence; instead, we used a TPS based heterogeneity correction to make the EPID dosimetry at par with the modern planning systems dose calculation accuracy. Heterogeneity correction can easily be incorporated in the back-projection technique as well.

The efficacy of accounting for the heterogeneity in EPID dosimetry is clearly depicted in Figure 2. It can be seen from panels D and E that gamma matching has significantly decreased with and without applying heterogeneity corrections.

The present technique of PTQA is useable only for the fixed-beam IMRT fields. Although it is theoretically possible to apply the same concept for the rotational arcs, the complexity of the process prevents us from doing so until the technique is completely automated. We are currently working on the automation of the technique.

This approach is likely the first of its kind to demonstrate EPID-based PTQA that accounts for the TPS-based heterogeneity correction. The present studies show that heterogeneity correction significantly increases gamma-matching results.

Heterogeneity correction plays a major role in EPID QA in both transit dosimetry and PTQA. In general, all other groups attempted to compare the EPID transit dosimetry result with the TPS generated values either via back-projection or forward projection methods without addressing the heterogeneity correction issue. This led to erroneous dosimetric results for cases associated with large heterogeneities.[6-7] It may be argued that our method is not completely independent of TPS calculation. We accept the demerit, as we have only one type of TPS available. The use of a single planning system for calculating the patient treatment plan and TPS heterogeneity may have its own advantages and disadvantages. The advantage is that EPID dosimetry uses the same dose calculation algorithm as the treatment planning dosimetry method. This overcomes the algorithm incompatibility problem between the EPID dose calculation software and TPS. The disadvantage is that EPID dosimetry is not completely independent of TPS. Two different TPS can be used, based on the availability, to make the dose calculation and heterogeneity calculation independent of each other. The use of TPS in QA was previously accomplished by Nelms and Simon[21] while constructing the 3D dose in 3DVH software. They used a planned dose perturbation technique to create the predicted delivered 3D dose from a TPS calculated dose and ArcCHECK (Sun Nuclear, CA) measured fluence. Furthermore, predicted and TPS calculated doses were compared in terms of DVH to quantify the dose difference between measured and delivered doses. Primarily, we have tested the technique for 45 patients of different subgroups because of the complexity of data acquisition and dose reconstruction. We are in process of automating this novel

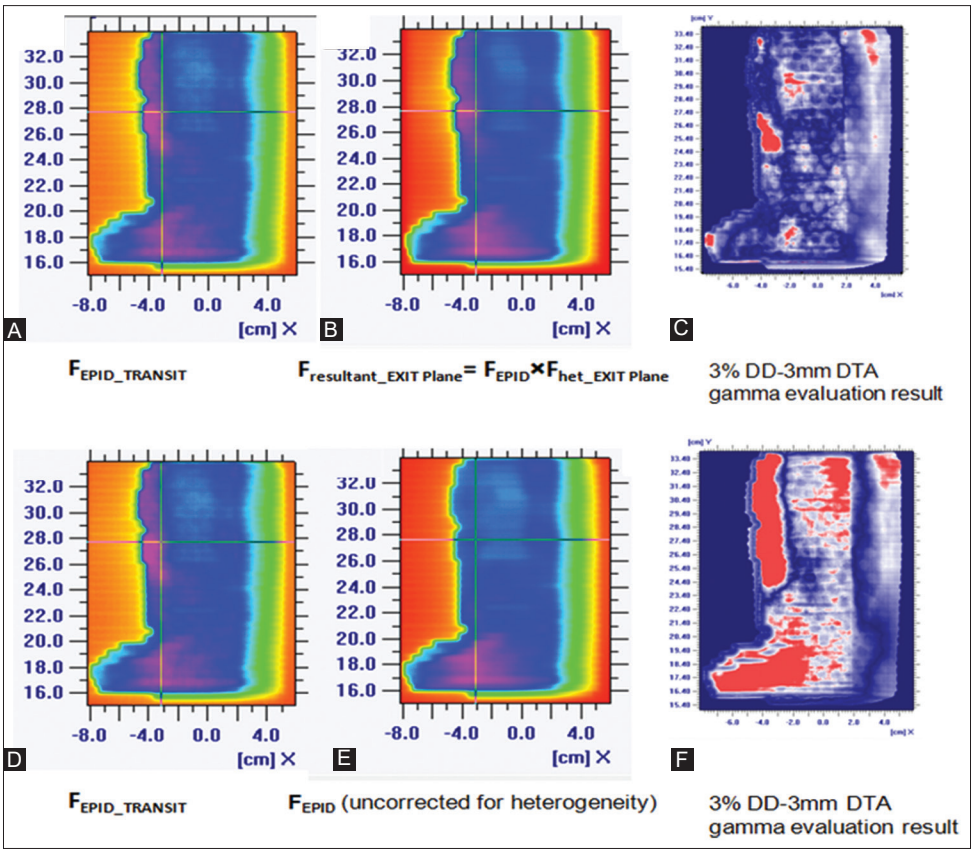

Figure 6: Pretreatment quality assurance: validation measurement result using transit dosimetry results for lower esophagus case. Panels A and D are same shows the electronic portal imaging device measured dose in the presence of patient ($F_{EPID\_TRANSIT}$). Panel B measured electronic portal imaging device fluence corrected for exit plane heterogeneity from TPS ($F_{resultant\_EXIT\ Plane} = F_{EPID} \times F_{het\_EXIT\ Plane}$). Panel C shows the gamma matching for A and B. Panel E is treatment planning system-generated fluence (F_{EPID}) uncorrected for heterogeneity correction from treatment planning system. Panel F: gamma matching between D and E

PTQA process, which will allow the end-user to seamlessly utilize it for routine clinical processes.

Conclusion

We have presented a novel PTQA technique for EPID forward dosimetry. This technique efficiently handles large heterogeneities that were unresolved when using the back-projection approach and is the first of its type to incorporate a TPS-based heterogeneity correction for EPID-based patient-specific QA. The demonstrated technique can be used for routine pretreatment with only one additional step, namely generating a single-attenuation plane for EPID heterogeneity correction.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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