EPID-based linear accelerator benchmarking using pixel sensitivity map

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Abstract. Conventional verification of linac performance is conducted by measuring percent depth dose (PDD) as well as beam profiles in a water tank, which is labor intensive and requires expensive beam scanning equipment. We present a novel method to benchmark the linac beam characteristics using pixel sensitivity map (PSM) corrected EPID images and to evaluate the feasibility of EPID-based beam benchmarking. A novel approach was developed to generate a two-dimensional (2D) PSM for EPIDs utilizing an alternating beam and dark-field image acquisition technique. The calculated PSM based on a recursive calculation algorithm was used to correct EPID pixel response. The acceptability of a benchmarked beam is based on its profiles being within predetermined tolerances. The PSM-corrected open field EPID images were compared for three photon energies (6 MV, 10 MV and 6FFF) between three TrueBeam and one Edge linacs with aS1200 imaging panels. The output factors were measured with EPID from 2×2 cm² to 40×40 cm². The differences in beam profiles and output factors from EPID were evaluated. The four dosimetrically similar linacs with less than 1% variation in PDD, profiles and output factors measured in water scans showed excellent agreement in the EPID profile measurements. The 1D Gamma of the PSM-corrected profiles between any two linacs showed 100% passing rate for 6 MV and 6 FFF and >97% for 10 MV with 1mm/1% criteria. The maximum difference of output factors was 0.18% among all the measurements except for 2×2 cm² with 0.6% difference. By preserving the beam dosimetry information, the PSM-corrected EPID images enable the possibility of validating the beam data of linac dosimetry and benchmarking linac performance with the common EPID detector.

1. Introduction
The dosimetric characteristics for linacs with the same vendor and nominal energy are known to be very similar [1]. The IROC data measured on over 50 Varian linacs demonstrated that all dosimetric data were within the clinical acceptance range of less than 1% [2]. Benchmarking that two machines are dosimetrically equivalent is a desired methodology that is performed between two or more linear accelerators to ensure patient portability. One of the advantages of beam benchmarking or ensuring that linear accelerators are dosimetrically equivalent is the improved efficiency and flexibility in patient treatments for institutions with multiple linacs where patient treatment can be delivered on any unit whose performance is within clinically acceptable limits without any change in the treatment parameters. Validation of beam performance is usually performed during commissioning and requires acquisition and processing of a significantly large amount of machine beam data [3]. The beam data measurements including percentage depth dose (PDD) and beam profiles are labor intensive, and the entire process is one of the most complex and error-prone in radiation oncology [4]. Incorrect output
factors and percentage depth doses were identified as some of the causes of failures [4]. In addition, the beam data measurements require expensive beam scanning equipment.

In this study, we present a novel method to benchmark the linac beam characteristics using pixel sensitivity map (PSM) corrected images measured with electronic portal imaging devices (EPIDs) and to evaluate the feasibility of EPID-based validation of beam properties. With excellent dosimetric characteristics, EPID has been widely used for patient dosimetry measurements and machine QA during the past decades [5]. There have been numerous publications on the use of EPID for QA of virtually every aspect of linac performance, and it has been recently used for all EPID daily QA [6] and rapid acceptance tests of linacs [7]. To utilize EPID for linac beam measurements and benchmarking linac performance, two major questions need to be answered: 1) Can EPID be used to measure the beam energy or quality? 2) Does the beam profile depend on the difference in response of individual pixels of EPID panels, as the EPID equipped on each linac may have a different response?

It is known that profiles or off-axis ratios (OAR) are sensitive metrics for verification of beam energy for both flattened and unflattened photon beams. The OAR or flatness measured either on the orthogonal axes or the diagonals was proposed as a sensitive and efficient way to monitor photon beam energy constancy [8]. Recently we have used EPID profiles for verification of beam energy and correlated the profile changes with the changes in PDD [7]. All these studies have shown that EPID can be used for the constancy check of beam quality. Unlike the conventional flood field calibration of EPID, the PSM approach is independent of beam profiles and separate detector sensitivity and beam profiles. In this study we improved the previously developed PSM approach [9, 10] based on an alternating beam and dark field technique (ABDF) and further removed the uncertainty of pixel response. The PSM-corrected EPID images were used to compare the dosimetric characteristics and for beam benchmarking.

2. Materials and Methods

Three Varian TrueBeam linacs and one Edge linac were recently commissioned. All these four linacs are equipped with aS1200 EPID panels. The water scan measurements of PDD, profiles, and output factors were performed to verify that the four linacs were dosimetrically equivalent.

Traditional flood field (FF) calibration is not an ideal method for dosimetric purposes, since it removes the beam profile characteristics from the image. The PSM provides the relative gain correction factor for each pixel and is applied to correct raw images. The PSM method provides several advantages: 1) Separation of detector properties (sensitivity) and beam profile; 2) Calibration is independent of the beam profile (no water tank measurements needed); 3) Calibration is independent of imager position. Figure 1 shows the principle process in the derivation of the PSM by acquiring several sets of EPID images with the panel shifted to different positions between each irradiation. Three open fields with the largest field size were first delivered with EPID shifts along the lateral and longitudinal directions by 50 pixels to calculate an initial estimate of the sensitivity map using the previously developed PSM algorithm [9, 10]. Two EPID images were then acquired at different vertical shifts. The initial PSM was then applied to the two images by considering the inverse square correction. The initial PSM was then applied to the two images by considering the inverse square correction. The initial PSM was corrected to minimize the difference of the two PSM-corrected images and to generate the intermediate PSM. When finished, the two PSM-corrected scaled images should be equal (except for the scaling). During Step 3 four small images were acquired with the same open field at four different quadrants of EPID. The four images were corrected using the intermediate PSM. The difference between any “small” images was fitted using a polynomial function for final tuning of the intermediate PSM. When done, the four small images should be equal after PSM correction.

After the PSM was calculated for each linac, an open field of 20×20 cm² was acquired to validate the profiles, and the raw images were corrected using the final PSM. To quantify the dosimetric equivalence, the 1D gamma analysis with 1mm/1% was compared for these machines. The output factors were also measured with EPID from 2×2 to 40×40 cm² open fields to compare for all three energies among these four linacs.
It is well known that the PSM procedure relies on the repetition of the same beam for all steps of this process [11]. The PSM procedure assumes no change in beam fluence for subsequent deliveries. Any variation of beam fluence can lead to systematic error propagation. To achieve the highest possible repeatability and avoid errors due to image lag and variation of fluence, the calibration images were acquired with ABDF. XML-scripts (Varian TrueBeam Developer Mode 2.5) were developed to define the imaging acquisition mode named “ABDF technique” that automated the entire acquisition process. During the beam-on time, 2 MUs were delivered for each beam-on image with modulated dose rate and synchronized acquisition to ensure that the maximum signal was derived without saturating the imager. The dark fields taken during the beam-hold period were later subtracted from the raw images to eliminate the background noise and residual signal when radiation had ceased. This process was repeated 100 times. The first 40 pairs of images were discarded to avoid fluence from a previous irradiation field. From the remaining 60 pairs of images, the average image with beam and average image without beam was calculated. The advantage of the ABDF technique was to eliminate the ghosting effects for each frame and therefore reproduce the true pixel signal per frame. A recursive algorithm coded was used to derive the PSM [9, 10].

Figure 1. Sketch of three steps of calibration to derive PSM. Step 1: The panel along lateral and longitudinal directions for initial PSM calculation; Step 2: The vertical panel shift to correct gradient errors in the sensitivity; Step 3: the panel shifts to acquire images at the four different quadrants to correct any remaining errors.

3. Results
Figure 2 shows the comparison of raw image and PSM corrected image acquired with the 20×20 cm² open field for 6 MV from one of the linacs. The raw image shows stripe patterns from the line readout mechanism along the longitudinal direction. The PSM-corrected image does not show this pattern and is more uniform. Figure 3 shows the beam profiles of the raw image for 6 MV from the four linacs. Though the water scans are equivalent, without correction, the raw beam profiles in both crossline and inline directions do not agree across the four machines. “Wiggling” and “spikes” in the beam profiles due to stripe patterns and noise are present in the profiles.
Figure 2. Raw image (a) and PSM corrected image (b) for one of the linacs.

Figure 3. Beam profiles of uncorrected EPID images. (a) crossline; (b) inline.

Figure 4 shows the profiles of PSM corrected images with 20×20 cm² of four linacs for three photon energies: 6 MV (a), 10 MV (b) and 6 FFF (c). The PSM corrected all the artifacts and noise and smoothed out the beam profiles. The 1D Gamma of the PSM-corrected profiles between any two linacs showed 100% passing rate for 6 MV and 6 FFF and >97% for 10 MV with 1mm/1% criteria. The four clinically equivalent linacs with less than 1% variation in PDD, profiles and output factors measured in water scans show excellent agreement in the EPID profile measurements.

The output factors measured from 2×2 cm² to 40×40 cm² with EPID are shown in Figure 5. The maximum difference of output factors was 0.18% among all the measurements except 2×2 cm² with a maximum difference of 0.6%.

The novel PSM calibration approach and EPID-based processes for beam benchmarking take only a few minutes for each beam energy and significantly improve the efficiency compared with water scanning.
4. Conclusion

We show that the beam profiles derived from the EPID measurement on four linacs are benchmarked after the PSM normalization. PSM-corrected EPID images enable the possibility of benchmarking linac performance with the common EPID detector.

5. References

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