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Use of Electronic Portal Image Detectors for Quality Assurance of Advanced Treatments

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Abstract. As the complexity of radiation therapy has increased, the need for quantitative dosimetric evaluation of treatment delivery has also increased. A growing number of investigations have expanded the use of EPIDs from anatomic applications to dosimetric verification. This work focuses on the applications of EPIDs for pre-treatment dosimetric verification of IMRT and intensity modulated arc therapy techniques. The advantages and disadvantages of these techniques are discussed along with methods to extrapolate to 3D dose verification applications.

1. Introduction

The evolution of radiation therapy treatment planning and delivery methods has required a similar evolution for the dosimetric methods for evaluation. Delivery techniques such as intensity modulated radiation therapy (IMRT) and intensity modulated arc therapy (IMAT) require more detailed spatial information. As the need for pre-treatment patient-specific quality assurance has increased, so have investigations into the use of electronic portal imager detectors (EPIDs). EPIDs offer advantages compared to other systems in that they are attached to the gantry and are sold with the majority of new accelerator purchases. They are also efficient to use and do not require the set up of any additional equipment once the system has been commissioned for such a purpose. However, the response of EPIDs to radiation is complex due to their composition. These systems were designed and optimized to require as little delivered dose as possible to obtain a high quality image that can be used for patient localization.

EPIDs have been investigated for both pre-treatment and transit dosimetry applications. These different types of portal dosimetry methods have been comprehensively reviewed by van Elmpt et al.[1] Transit or in vivo dosimetry methods have been developed and reported on by investigators at the Netherlands Cancer Institute (see conference paper by Mijnheer et al).[1-5] These methods typically utilize the commercial configuration of the device. Additional software tools and acquisition methods have been developed with EPIDs to verify the accuracy of a delivered treatment pre-treatment without a patient and with or without a phantom present. The majority of these pre-treatment investigations have been performed utilizing commercial EPID systems in an indirect detection configuration where the system includes a scintillation-layer as part of the manufacturer supplied configuration. Other investigators have used direct detection configurations where no scintillation layer is present. This work focuses on methods developed for amorphous silicon-based systems for pre-treatment quality assurance methods.

2. EPID Dosimetry with Standard Configurations

Amorphous silicon EPIDs have been investigated for dosimetric applications for IMRT and arc therapy techniques. Reliable use of the system requires commissioning of the planning and delivery system prior to development of the EPID-based program. Then, it may be appropriate to establish a pre-treatment QA program based on calculations in the EPID compared with the EPID response. These methods typically rely on determining the appropriate parameters of operation of the EPID and accurate determination of correction factors and the accuracy of the calculation of a predicted portal dose image (PDI).[6-12] The features of the measurement are affected by the frequency of the data acquisition and communication speeds. The response itself can be affected by ghosting and lag. The response of these systems depends on the field size.

The presence of the scintillator results in an increased sensitivity to low energies. For example, the effect of the different layers of material and backscatter on the detector response as a function of energy has been quantified using Monte Carlo calculations.[13] Therefore the response of the system is dependent on the energy spectrum of the delivered beam. In some investigations, additional buildup is added to provide additional attenuation of the beam. Initial investigations demonstrated a clear dose rate effect due to saturation of the detector.[8]

2.1. Calculating the Predicted Portal Dose Image (PDI)

For pre-treatment QA, the EPID response is measured and then compared to the predicted portal dose image (PDI). This method is used to verify the accuracy of the intended fluence. The measured response is compared to a calculation in the imager rather than converting the imager response to dose in water. Initial methods used pencil beam methods to predict the portal dose image.[8] Other methods involved calculating separate fluences for the primary and scatter components.[6, 7] More recently, investigators have used Monte Carlo to create EPID-specific dose kernels. For example, one method uses Monte Carlo to incorporate details of the multileaf collimator design such as transmission, tongue-and-groove, and curved leaf ends.[9] In another study, Monte Carlo was used to generate imager-specific dose kernels to investigate different thicknesses of backscattering.[14] Other considerations included determination that the effect of backscatter due to the metallic components of the support arm can be as much as 6% for large fields.[15]

With the corrections applied, the majority of these studies found agreement of >90% of the points to be within criteria 2%/2 mm for dose and distance, respectively for IMRT and IMAT deliveries. These studies demonstrate the complexity of modeling required for robust use of EPIDs for IMRT pre-treatment QA.

2.2. Measuring the Portal Dose Image (PDI)

When operated in an integrative mode during delivery, amorphous silicon EPIDs have been found to have a reproducible response which is essential for dosimetric applications.[7, 8] Investigators have characterized the response for a range of field sizes, doses, dose rates, and source-to-detector distances. Continuous acquisition mode has also been investigated for EPID verification for IMRT and IMAT delivery methods to allow for discrimination of time-based information. In this mode, some information is lost during the readout and the system was determined to have a non-linear response to dose for low doses.[12] The system was found to be reliable for the IMRT and arc therapy fields that were evaluated. For arc and IMRT applications, there are discrepancies for deliveries of low monitor units.[8, 10, 12] These need to be further evaluated to ensure that EPID techniques are only used in validated situations.

3. Dosimetry with Direct Detection Configurations

Due to the difficulties in modeling scatter and the fact that the measured response differs substantially from dose in water, work has also been done using amorphous silicon-based systems in a direct detection configuration.[16-20] Because these systems do not have a scintillator, the overall signal is much lower. The measured signal is converted to dose more simply than with indirect detection

systems although there the dark field must be adequately measured. The devices can be operated in continuous or integrated modes with considerations similar to commercial systems about loss of data in the continuous acquisition mode.[16, 18] The configuration results in measured results that are much more similar to those in water, even with minimal backscatter.[20]

4. 3D Applications

In vivo dosimetry methods rely on the backprojection of the measured response to a plane in the patient or phantom.[1] With cone beam CT data more readily acquired as part of a patient's treament, 3D verification of the actual delivered dose is becoming feasible. Methods for 3D dose verification have been developed for hypofractionated lung treatments[4, 21] and prostate, rectum, and head-and-neck treatments[5]. Methods are being developed to account for artifacts in the cone beam CT images.[22, 23] Monte Carlo methods have been used to reconstruct the dose in a phantom as a function of the measured exit dose for an IMRT treatment.[24] These methods promise must more information about the accuracy of the delivered dose to patients.

5. Summary

As radiation therapy continues to increase in complexity, it is crucial to have validated and easy to use methods to verify that the correct treatment plan was delivered to the patient. Information that has previously been obtained solely for adaptive therapy purposes can be used to develop more sophisticated models of the patient over the course of treatment. Methods to use commercial EPID systems for verification of IMRT and IMAT treatments have been developed and are in use in some centers. When used in the standard configuration (indirect mode), a number of correction factors must be applied to the measurement and to properly calculate the predicted portal dose image. Transit dosimetry methods have also been developed and the derived information is being coupled successfully with cone beam CT information to develop models of the 3D delivered doses. The accuracy of these methods must be validated with dosimetry systems of known performance. From a safety perspective, the use of EPID information to reconstruct 3D doses provides much more information about the quality of a patient delivery. This area is expected to mature over the next few years.

Table 1. Summary of investigations into the use of EPIDs for pre-treatment verification in a standard configuration for advanced technology treatments.

First Author/Year	Method	Conditions	Limitations
van Esch et al. 2004	Measurement: integrated acquisition mode; averaged gray scale image converted to portal dose image (PDI) Calculation: predicted PDI based on a pencil beam method	3x3 cm^2 to 25 x25 cm^2 for SDD=105 cm; SMLC/DMLC	Adversely affected by saturation of the detector at 600 mu/min dose rate
Chytyk et al. 2009	Improved calculation: Two-source fluence model with focal and extra-focal sources; more detailed modeling of jaws and MLC; Monte Carlo used to derive EPID-specific	Derived parameters with 1x1 cm^2up to 20x20 cm^2 fields Tested: Fields for 10 prostate and 10 oropharyngeal patient plans	Patient scatter not modelled and therefore not implemented for transit dosimetry

	dose kernels		
McCurdy et al. 2009	Measurement: continuous acquisition mode	IMRT and IMAT techniques	Difficulties with verification of low MU; significant discrepancies from ion chamber measurements below 50 MU
Iori et al. 2010	Measurement: intensity-modulated arc therapy; accessory mount clamped between EPID and collimator housing to keep EPID position stable during rotation Calculation: pencil beam kernels derived from measurements	23 Treatment fields delivered with both IMRT and IMAT techniques	Compared to an ion chamber 10% disagreement for ~15 MU; (3.3% discrepancy ≥100 MU)

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