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EPID and IMRT

Dosimetric pre-treatment verification of IMRT using an EPID; clinical experience

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Abstract

***Background and purpose*: In our clinic a QA program for IMRT verification, fully based on dosimetric measurements with electronic portal imaging devices (EPID), has been running for over 3 years. The program includes a pre-treatment dosimetric check of all IMRT fields. During a complete treatment simulation at the linac, a portal dose image (PDI) is acquired with the EPID for each patient field and compared with a predicted PDI. In this paper, the results of this pre-treatment procedure are analysed, and intercepted errors are reported. An automated image analysis procedure is proposed to limit the number of fields that need human intervention in PDI comparison.**

***Materials and methods*: Most of our analyses are performed using the γ index with 3% *local* dose difference and 3 mm distance to agreement as reference values. Scalar parameters are derived from the γ values to summarize the agreement between measured and predicted 2D PDIs. Areas with all pixels having γ values larger than one are evaluated, making decisions based on clinically relevant criteria more straightforward.**

***Results*: In 270 patients, the pre-treatment checks revealed four clinically relevant errors. Calculation of statistics for a group of 75 patients showed that the patient-averaged mean γ value inside the field was 0.43 ± 0.13 (1 SD) and only 6.1 ± 6.8% of pixels had a γ value larger than one. With the proposed automated image analysis scheme, visual inspection of images can be avoided in 2/3 of the cases.**

***Conclusion*: EPIDs may be used for high accuracy and high resolution routine verification of IMRT fields to intercept clinically relevant dosimetric errors prior to the start of treatment. For the majority of fields, PDI comparison can fully rely on an automated procedure, avoiding excessive workload.**
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Keywords: Quality assurance; Intensity modulated radiotherapy; EPID; Portal dosimetry

For many tumor sites the use of intensity modulated radiotherapy (IMRT) has proven a powerful technique to achieve a better dose conformity to the tumor volume and an increased sparing of normal tissues and organs at risk. In practice, this is only achieved if the planned fluence is delivered accurately at the treatment unit. Errors may arise if (a) the calculated leaf sequence does not accurately result in the fluence pattern used by the treatment planning system for dose calculation. (b) The treatment plan is not correctly transferred to the accelerator or (c) the treatment machine is not functioning correctly, either mechanically or dosimetrically. Pre-treatment verification of fluence delivery is an effective method of ensuring the accuracy of IMRT treatments. Since such measurements are performed without a patient in the beam, they will have no impact on the patient and any errors that may be present can be solved before starting the first treatment fraction.

Pre-treatment verification of IMRT fields may be performed using ionization chambers, thermoluminescent detectors or diodes at a single or a few points, potentially yielding a limited accuracy due to gradients that often exist in IMRT fluence maps. 2D devices such as diode or ionization chamber arrays contain more measurement points, but still a resolution higher than 1 cm is rarely achieved. Film measurements [1,2,4,28] provide high resolution 2D data, but require digitization of the measured data, which is time consuming. Pre-treatment verification using an electronic portal imaging device (EPID) [7,19,27] provides direct high resolution 2D digital data, and is therefore, much faster.

Two studies on IMRT pre-treatment verification for a large number of patients based on film measurements have been published [2,4], but results of measurements with an EPID for a large number of patient plans are lacking in the literature. Our institution has a long experience with the use of fluoroscopic EPIDs for dosimetric quality assurance [9—12,18—20,24,25]. Pre-treatment verification of IMRT, delivered with dynamic multileaf collimation on 2 Clinacs 2100C (Varian Associates, Palo Alto, CA) equipped with an

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80-leaf MLC (leaf width 1 cm), has been performed with these EPIDs for 270 patients in the past 3 years. In this study, the results are evaluated. Disagreements between measurement and prediction are described and errors in fluence delivery that have been successfully intercepted by the pre-treatment verification are reported.

To quantify the results, the γ evaluation method proposed by Low et al. [14] was used. This concept incorporates both dose difference and distance to agreement into a single measure. Especially for IMRT profiles with large dose gradients, this approach has advantages over an evaluation based on dose difference maps, where large differences may be found in high dose gradient areas that are only slightly shifted locally. Several scalar parameters based on the γ evaluation [3–6,23] are used to quantify the overall agreement between measured and predicted portal dose images (PDI). Additionally, a novel metric based on areas with γ values larger than one is introduced to evaluate the clinical relevance of observed discrepancies.

A final goal of this study was to define parameters and criteria that can be used for a consistent (semi-) automatic evaluation of the pre-treatment images. The objective was to develop a procedure that automatically selects and approves fields with only small and clinically irrelevant differences between the measured and predicted PDI, leaving the remaining ones for further review by a human observer.

Materials and methods

IMRT pre-treatment verification: current practice

In our institute, the fluoroscopic Theraview NT (TNT) EPID (Cablon Medical-Theraview Technology, Leusden, The Netherlands) is used for portal imaging. This system is equipped with a low-noise cooled CCD camera. Its stable response [0.4% (1 SD)], the simultaneous integration of signal in 1024×1024 pixels, and a dead time between the acquisition of frames of only 0.2 ms make this EPID well suited for dosimetric measurements in IMRT fields produced with dynamic multileaf collimation [9].

For the pre-treatment measurements, the focus to fluorescent screen distance is set to 150 cm, allowing for a maximum field of view of 22×22 cm^2, defined at isocenter height. EPID images are acquired for every treatment field of an IMRT patient plan before the start of the first treatment fraction. Measured pixel values are first corrected for dark current and a minor non-linearity in response of the EPID system [9]. Next, corrections are performed for optical cross-talk by deconvolution with a point spread function and for sensitivity variations across the EPID plane, yielding a PDI [18].

The Cadplan TPS (Varian Associates, Palo Alto, CA) is used to predict for each treatment field a PDI at the plane of the fluorescent screen of the EPID in absence of the patient. This prediction is based on a convolution of a pencil beam kernel with the planned fluence map [19]. The calculated PDIs are imported in the database of the TNT software using Dicom. The TNT software has several tools for comparison of the measured and predicted PDIs: 2D portal dose difference maps, average dose difference profile per leaf and a γ evaluation.

Current practice in our institution is to start the PDI comparisons with visual inspection of the γ image, using a 3% *local* dose difference and a 3 mm distance to agreement as reference values (in the following referred to as 3% local/3 mm). For these analyses, γ values are only derived in the area, where the dose is higher than 10% of the maximum dose in the predicted PDI (as done for all the investigations in this paper), in order to exclude low dose areas outside the actual treatment field. By exclusion of such area from the analysis it is very unlikely to ignore large errors, because in none of our pre-treatment results such low dose areas were observed inside the treatment field, probably due to the Cadplan inverse planning software and DMLC delivery method being used. In case of an excessive amount of pixels (>15%) outside the tongue-and-groove areas with a γ value larger than one, or if these pixels are clustered in areas larger than about 2 cm^2, further investigations are performed. These comprise an analysis of dose difference profiles, and an assessment of the potential clinical impact (a somewhat enlarged deviation in only one of the fields may be considered less relevant, especially when located in a low dose area). In case of large, possibly clinically relevant deviations, additional measurements at the treatment unit are performed, for example, using ionization chambers.

Retrospective analysis of pre-treatment verification results

For 75 patients (with a total of 316 fields, generally 4–5 fields per patient plan) that were treated in the past few months, the results of the pre-treatment verification were, retrospectively analysed in greater detail. The group comprised 58 patients with head and neck cancer, 2 with prostate cancer, 11 with rectum cancer and 4 with cervical cancer. For this purpose, three scalar parameters were calculated from the γ images to summarize the results: (a) the average γ value of the image (γ_{avg}) [5,23], (b) the near-maximum γ value (i.e., the value that is only exceeded by 5% of the points, γ_{95} and (c) the number of points with a γ value larger than one (n_{reject}) [4–6,23]. As discussed in Discussion, this paper is mainly based on 3% local/3 mm reference values. To compare with the literature [2,4,15,23], evaluations were also performed for 5% local/3 mm and 3% global/3 mm. In the latter case the 3% dose difference was taken with respect to the *maximum* dose in the predicted PDI.

To have a measure that is more directly linked to the clinical relevance of observed differences, the size of areas with γ values larger than one has been introduced as an additional evaluation parameter. With this parameter it is possible to distinguish cases with the rejected points spread out over the field from those with rejected points concentrated into a single or a few larger areas, the latter with a higher associated risk for a clinical impact. This analysis is closely related to what is presently done by visual inspection of the γ images.

For assessment of areas with all γ values larger than one, the γ matrices were exported from the TNT software and used as input for a program written using the IDL software package (Research Systems, Inc.). The PDI predictions do