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Quality assurance

3D dose reconstruction for clinical evaluation of IMRT *pretreatment* verification with an EPID

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Abstract

***Background and purpose*: Pretreatment verification with an electronic portal imaging device is an important part of our patient-specific quality assurance program for advanced treatment techniques. Up to now, this verification has been performed for over 400 IMRT patient plans. For every treatment field, a 2D portal dose image (PDI) is measured and compared with a predicted PDI. Often it is not straightforward to interpret dose deviations found in these 2D comparisons in terms of clinical implications for the patient. Therefore, a method to derive the 3D patient dose based on the measured PDIs was implemented.**

***Methods and materials*: For reconstruction of the 3D patient dose, the actual fluences delivered by the accelerator are derived from measured portal dose images using an iterative method. The derived fluence map for each beam direction is then used as input for the treatment planning system to generate an adapted 3D patient dose distribution. The accuracy of this method was assessed by measurements in a water phantom. Clinical evaluation of the 3D dose reconstruction was performed for 17 IMRT patients with different tumor sites. Dose differences with respect to the original treatment plan were evaluated in individual CT slices using dose difference maps and a 3D γ analysis and by comparing dose-volume histograms (DVHs).**

***Results*: The measurements indicated that the accuracy of the 3D dose reconstruction was within 2%/2 mm. For the patients observed dose differences with respect to the original plan were generally within 2%, except at the field edges and in the sharp dose gradients around the planning target volume (PTV). Gamma analysis showed that the dose differences were within 2%/2 mm for more than 95% of the points in all cases. Differences in DVH parameters for the PTV and organs at risk were also within 2% in nearly all cases.**

***Conclusion*: A method to derive actual delivered fluence maps from measured PDIs and to use them to reconstruct the 3D patient dose was implemented. The reconstruction eases the estimation of the clinical relevance of observed dose differences in the pretreatment measurements.**
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Keywords: Quality assurance; Intensity modulated radiotherapy; EPID; Portal dosimetry

The increased use of advanced techniques like intensity modulated radiotherapy (IMRT) for treatment of cancer patients puts higher demands on the quality assurance (QA) program for verification of dose delivery. In our clinic, a patient-specific IMRT QA protocol is under development that consists of several components. First, to verify that the calculated 3D dose distribution is highly accurate, the treatment plan of each patient is recalculated with a fully independent dose engine. Second, to check the proper transfer of treatment parameters and the correct execution of the plan at the treatment unit, measurements with an electronic portal imaging device (EPID) are performed prior to the start of the actual treatment. By comparing realized portal dose images with predictions, errors in the delivered fluence maps can be intercepted before any dose is delivered to the patient, thereby avoiding any possibly harmful clinical impact. During each treatment fraction, in vivo measurements are performed with the EPID to verify the delivered IMRT fields. Using the so-called Split IMRT Field Technique (SIFT) [10], errors in the delivered fluence maps of 1—2% can be detected, even if large changes of the patient anatomy with respect to the planning CT scan exist. At the same time, information about patient set-up and geometrical changes within the patient may be obtained, allowing reconstruction of the actually delivered 3D dose to the patient during treatment.

Until recently, IMRT pretreatment verification with EPIDs was performed in our clinic by verification of the fluence delivery of each individual treatment field of a patient plan [7,11]. For those measurements, a fluoroscopic, cooled CCD-camera based EPID was used [1,2]. In a recent publication [11] the results of the measurements were quantified in

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more detail using the average γ value inside the treatment field and the percentage of points with a γ value larger than 1. It was demonstrated that the analysis of joined areas with γ values larger than 1 aided the assessment of possible clinical implications of observed deviations. However, it remains difficult to derive the impact of observed deviations between measured and predicted portal doses in a single field on the overall 3D patient dose distribution. This impact depends on the total number of treatment fields in the IMRT plan, the relative dose contributions of the different beams and on the deviations in each of the fields. To ease interpretation of the clinical relevance of observed pretreatment portal dose deviations in individual treatment fields, a 3D reconstruction of the patient dose distribution based on the measured fluences in all treatment fields and the planning CT scan may be applied. This allows the use of standard tools such as dose-volume histograms (DVHs) for the comparison of the originally planned and reconstructed delivered dose distribution.

The use of 3D dose reconstruction for the evaluation of pretreatment measurements has been previously described [8,9]. Renner et al. [8] used film measurements to derive the delivered fluence maps for each beam direction. Based on those fluences a dose reconstruction was performed using a pencil beam superposition algorithm that was independent of that of the planning system. For comparison with the original treatment plan they suggest using the standard deviation of the dose differences and an analysis of the isocenter dose and hot spots. Steciw et al. [9] described a similar approach for measurements with an amorphous silicon flat panel EPID. To account for signal spread in the EPID due to radiation and optical scatter, measured 2D EPID images were deconvolved with kernels derived by Monte Carlo simulations. The resulting fluence maps were used as input to the treatment planning system (TPS) to perform a 3D dose reconstruction. Compared to the original patient plan, large differences were observed in high gradient regions, leading to clinically significant dose differences in some organs at risk. From the good agreement of the reconstructed dose with TLD measurements, they concluded that those differences were to a large extent due to an inaccurate modeling of the fluence in the TPS, prior to the dose convolution.

In this study, an iterative method using CCD-camera based EPID measurements is described to derive delivered fluence maps from measured PDIs and to use these maps to reconstruct the 3D patient dose. The concept of this approach is described in detail. The method is validated experimentally to assess its accuracy. Clinical evaluation of the dose reconstruction is reported for 17 patients treated with IMRT.

Methods and materials

Measurement and prediction of portal dose images

For the measurements of 2D PDIs a fluoroscopic Theraview NT (TNT) EPID (Cablon Medical — Theraview Technology, Leusden, The Netherlands) with a cooled CCD camera is used. This system has shown to be well suited for dosimetric measurements for IMRT fields produced with dynamic multileaf collimation, because of its stable response, a short deadtime of only 0.2 ms between acquisition of frames and its simultaneous integration of signal in 1024×1024 pixels [1]. Due to the cooling, image degradation related with radiation damage to the CCD chips is low. Therefore the life time of these cameras is high (up to 5 years), avoiding frequent dosimetric re-calibration. For the 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.

The dosimetric calibration of the EPID is entirely based on the EPID images of square fields [3]. To derive position dependent crosstalk kernels 2×2 cm^2 off-axis fields are used [2]. In addition, EPID images are acquired for symmetric square fields ranging from 6×6 cm^2 up to 40×40 cm^2 to derive the screen kernel that describes the conversion of fluence into visible light from the fluorescent screen, the open beam profile, the local epid sensitivity and the impact of head scatter on the measured on-axis EPID signal. All images are normalized to the on-axis grey value measured for a 10×10 cm^2 field.

For pretreatment verification of IMRT profiles delivered with dynamic multileaf collimation at a Clinac 2100C (Varian Associates, Palo Alto, CA) equipped with an 80-leaf MLC (leaf width 1 cm), EPID images are acquired without a phantom in the beam for every treatment field of an IMRT patient, before the start of the first treatment fraction. The acquired images are then converted into measured PDIs, by correcting for dark current and a small non-linearity of the CCD-camera response [1], removal of the crosstalk contribution and normalization [3]. For PDI prediction, the calculated fluence maps are exported from the Cadplan TPS (Varian Associates, Palo Alto, CA). These fluences are corrected for head scatter, multiplied with the open beam profile and convolved with the screen kernel to obtain the predicted PDI [3].

Dose reconstruction algorithm

To reconstruct the 3D patient dose, delivered pretreatment fluence maps for each treatment field are derived from the PDIs measured without a phantom in the beam using an iterative method that is similar to the method described by McNutt et al. [5]. In contrast to our PDI measurements, McNutt et al. measured the fluence behind a phantom. In the first iteration, the measured and predicted PDIs are compared, and the original fluence map is multiplied with the relative dose differences between these PDIs to derive the first estimate of the delivered fluence. With this modified fluence, a new portal dose image is predicted, which is again compared to the measured PDI to yield an adapted fluence map. This process continues until the root mean square of the relative differences between the measured and the predicted PDIs is minimized. The iteration stops when the root mean square difference is less than 0.5% or if the change between successive iterations is less than 0.05%. This convergence is always reached within 10 iterations; while usually less than 5 iterations are needed. The fluence map that is obtained at that point is imported into the TPS replacing the original fluence file. With the