Current status of 3D EPID-based in vivo dosimetry in The Netherlands Cancer Institute

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Abstract. 3D in vivo dose verification using a-Si EPIDs is performed routinely in our institution for almost all RT treatments. The EPID-based 3D dose distribution is reconstructed using a back-projection algorithm and compared with the planned dose distribution using 3D gamma evaluation. Dose-reconstruction and gamma-evaluation software runs automatically, and deviations outside the alert criteria are immediately available and investigated, in combination with inspection of cone-beam CT scans. The implementation of our 3D EPID-based in vivo dosimetry approach was able to replace pre-treatment verification for more than 90% of the patient treatments. Clinically relevant deviations could be detected for approximately 1 out of 300 patient treatments (IMRT and VMAT). Most of these errors were patient related anatomical changes or deviations from the routine clinical procedure, and would not have been detected by pre-treatment verification. Moreover, 3D EPID-based in vivo dose verification is a fast and accurate tool to assure the safe delivery of RT treatments. It provides clinically more useful information and is less time consuming than pre-treatment verification measurements. Automated 3D in vivo dosimetry is therefore a prerequisite for large-scale implementation of patient-specific quality assurance of RT treatments.

1. Introduction

The use of *in vivo* dosimetry (IVD) in external beam radiotherapy (EBRT) has been addressed in many studies [e.g. 1-3]. In these papers a number of serious errors were identified that could not have been detected by other quality assurance (QA) checks, for instance by means of pre-treatment measurements. In addition to being able to detect major errors, the main application of IVD is to assess all clinically relevant differences between planned and delivered dose. In a recent paper the main characteristics of the most commonly applied IVD systems and their clinical use during EBRT have been summarized [4].

Despite the increasing use of EPIDs for dosimetry purposes [5, 6] only few groups have implemented *in vivo* EPID dosimetry in the clinic. Nijsten *et al* [2] presented an analysis of the results of routine EPID dose measurements obtained by correlating the dose measured with an EPID on the central beam axis with dose values at 5 cm depth. Piermattei *et al* [7] reported the first results of a national Italian *in vivo* dosimetry project in which a simple method was applied for the *in vivo* determination of the midplane dose using the central pixel values of an EPID. Recently Berry *et al* [8] applied an in-house developed algorithm to compare transit dosimetric EPID images, acquired during patient treatment, with predicted transit images. All these approaches verify the dose either at a point or in 2D.

In the Netherlands Cancer Institute (NKI) back-projection algorithms have been implemented for the 2D [9] and 3D dose verification [10] of intensity-modulated radiotherapy (IMRT) using amorphous silicon (a-Si) type of EPIDs, and more recently for the 3D verification of volumetric-modulated arc therapy (VMAT) [11]. In this presentation we will elucidate the current status of 3D EPID-based *in vivo* dosimetry as performed routinely in the NKI.

2. Materials and methods

Patient treatments are performed in our institution using SL20i linear accelerators (Elekta, Crawley, UK) having 6 and 10 MV photon beams. The linacs are equipped with MLCi (2x40 1cm leaves) or Agility (2x80 0.5cm leaves) MLCs and PerkinElmer RID 1680 AL5 amorphous silicon EPIDs (Elekta iViewGT).

Our EPID dosimetry method is a measurement-based approach applying a fast and simple 3D back-projection algorithm in combination with the planning CT data of a patient or phantom [9, 10]. For image acquisition during VMAT delivery, the in-house developed EPID acquisition software has been adjusted to save every detector frame separately (~ 3 frames/s), together with the accompanying gantry angle [11]. For dose verification of treatments of sites having tissue heterogeneities, a modification of our algorithm using the "*in aqua vivo*" approach is applied [12]. Phantom measurements showed that planned and measured dose values in the volume encompassed by the 50% isodose surface generally agree within 2% [10-12].

Treatment plans are generated with the clinical version of our treatment planning system (TPS) (Pinnacle v9.2, Philips Medical Systems, Eindhoven, The Netherlands), which includes the "SmartArc" module for VMAT plan generation. Reconstructed 3D dose distributions from acquired EPID images are compared with planned dose distributions using 3D γ-evaluation within the 50% isodose surface using global 3%/3mm criteria. All curative patients at NKI are irradiated either with an IMRT or VMAT technique; all others with a 3D conformal radiotherapy (3DCRT) technique. Almost all are verified by means of EPID-based *in vivo* dosimetry during three fractions in the first week of their treatment. Exceptions are single fraction irradiations, where both *in vivo* and pre-treatment verifications are performed, and when large field sizes are involved that will damage the EPID electronics.

New software tools were clinically introduced to allow automated image acquisition, to periodically inspect the record-and-verify database, and to automatically run the EPID dosimetry software [13]. The results of the analysis of the comparison of the EPID-reconstructed and planned dose distribution are available within a few minutes after delivery. Alerts are immediately raised without any human intervention when deviations are outside clinical criteria.

3. Results and discussion

The implementation of our 3D EPID-based *in vivo* dosimetry approach enabled the replacement of pre-treatment verification for more than 90% of the IMRT/VMAT treatments. The process has been integrated in our clinical workflow, and about 2,100 IMRT, 1,700 VMAT and 1,400 3DCRT treatments were verified in 2013. With our current set of clinical tolerance levels, approximately 20% of these verified plans showed deviations that required inspection by a medical physicist. After the inspection work, most of these deviations were found not to be clinically relevant. Only about one out of 300 verifications required consultation with the responsible radiation oncologist. These deviations were mostly patient-related (e.g. due to tumour shrinkage or disappearance of lung atelectesis) or due to changes in treatment parameters between planning and delivery (e.g. due to using wrong CT data or missing bolus during CT scanning), and could not have been traced with pre-treatment verification. The following example illustrates our procedure.

An EPID dosimetry report is automatically generated for each *in vivo* dose verification providing the mean γ (γ_{mean}), the 99th percentile (the near maximum γ value) ($\gamma_{1\%}$), and the difference in isocenter dose (ΔD_{isoc}) determined with the EPID and the TPS (see figure 1). A green dot in the EPID dosimetry report means that all alert criteria are within tolerance level ($\gamma_{mean} \leq 0.5$, $\gamma_{1\%} \leq 2$, and $\Delta D_{isoc} \leq 3\%$), a

yellow dot indicates that at least one of the alert criteria is outside tolerance level but still within action level ($0.5<\gamma_{mean}\leq1.0$, $2<\gamma_{1\%}\leq4$, and $3\%<\Delta D_{isoc}\leq5\%$), and a red dot indicates that at least for one of the evaluation criteria the error is outside the action level ($\gamma_{mean}>1$, $\gamma_{1\%}>4$, and $\Delta D_{isoc}>5\%$), i.e. it needs immediate action of a medical physicist. Note that a signed gamma analysis display is used; yellow and red mean that the EPID dose values are higher than in the plan, while green and blue display EPID doses lower than the corresponding data in the plan.

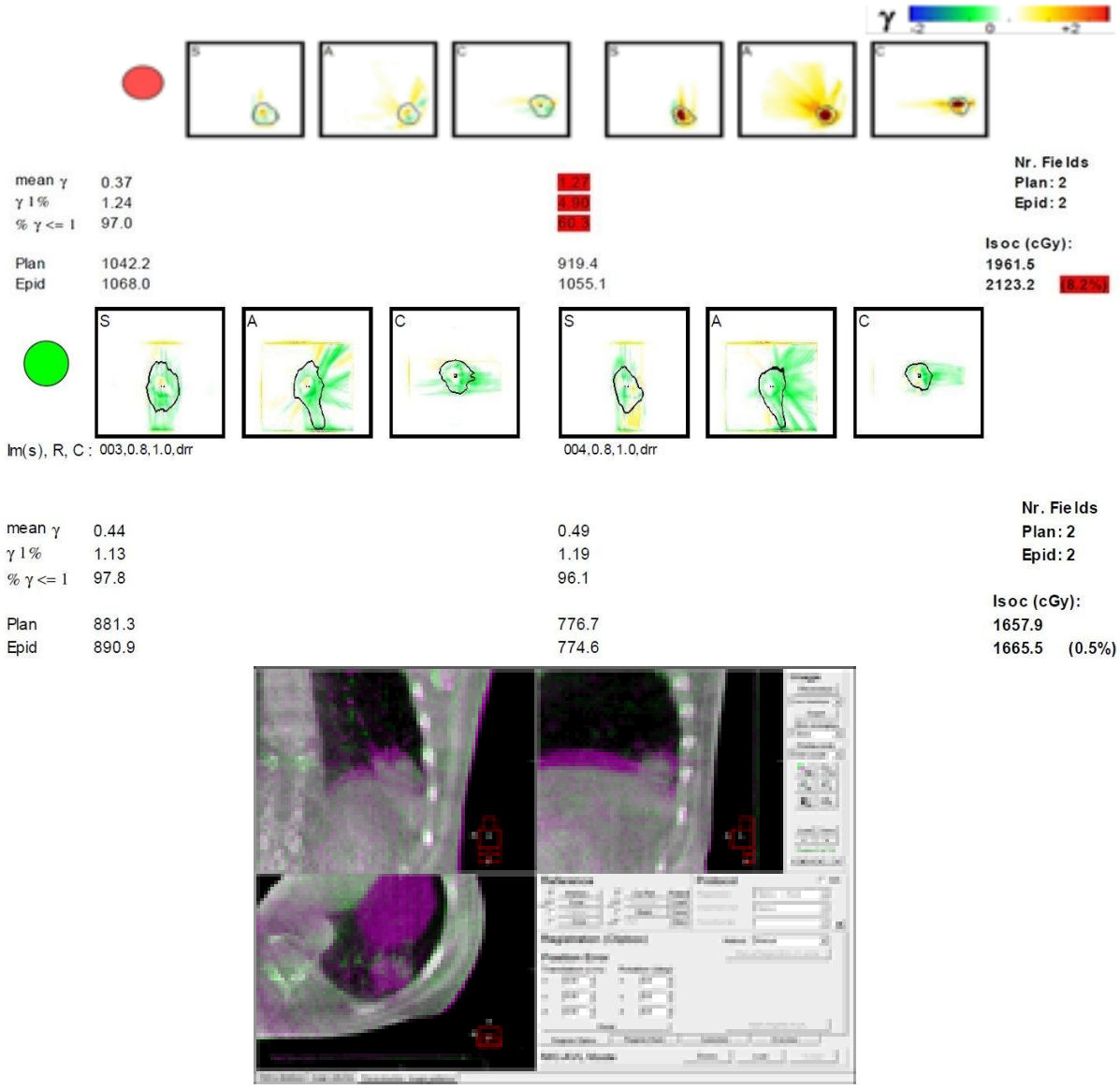

Figure 1. Results of a 3D EPID-based in vivo dose verification of a dual arc hypo-fractionated VMAT treatment of a lung cancer patient (top) and of a phantom measurement (middle) of the same irradiation. Indicated are the results of a 3D gamma evaluation in a sagittal, axial and coronal plane through the isocenter within the 50% isodose surface. The bottom part shows a comparison of a cone-beam CT scan (green) with the planning CT scan (purple) after the second arc in the three orthogonal planes.

The data presented in the upper part of figure 1 show that the results for the first arc were within acceptance criteria, but the data for the second arc were outside the action level. In order to verify if the plan was correctly calculated and delivered, a phantom measurement using the same irradiation

conditions as used during the patient treatment was performed. The results shown in the middle part of the figure indicate that all evaluation statistics are within tolerance/action level. Inspection of the cone-beam CT scan made after the second arc as shown at the bottom part of the figure indicates a baseline shift of about 1.5 cm between the two arcs. As a result of such observations, in-line cone-beam CT scans [14] are now made routinely of both arcs of hypo-fractionated lung VMAT treatments.

4. Conclusions

Our EPID dosimetry approach is a fast and accurate method for 3D in vivo dose verification of RT treatments. It provides clinically more useful information and is less time consuming than patient-specific pre-treatment dose verification. Automated 3D in vivo dosimetry is therefore a prerequisite for large scale implementation of patient-specific QA of RT treatments.

5. References

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