

Technical Note

In vivo dosimetry with an electronic portal imaging device for prostate cancer radiotherapy with an endorectal balloon[☆]

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ABSTRACT

Electronic portal imaging device-based *in vivo* dosimetry with a commercial product was performed for 10 prostate cancer patients treated with an air-filled endorectal balloon. With the conventional *in vivo* method the verification results were outside of our clinical acceptance criteria for all patients. The *in aqua vivo* method, originally developed for lung cancer treatments, proved to be a practical solution to this problem. On average the percentage of points within γ agreement of 3% and 3 mm significantly improved from $90.9\% \pm 2.5\%$ (1SD) for the conventional *in vivo* method to $99.0\% \pm 1.0\%$ (1SD) for the *in aqua vivo* method.

1. Introduction

In radiation therapy the delivery of the correct dose to the correct location is of utmost importance [1]. As part of the quality assurance, (complex) individual patient treatments are often verified by measurements. These patient-specific quality control (QC) measurements can be performed prior to treatment (“pretreatment”) or during treatment (*in vivo*). Historically, point measurements are used, but these are far from ideal for modern intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) due to the many dose gradients [2–4]. 3D *in vivo* dose verification of radiation treatments is an attractive QC method, because it offers the possibility to verify the dose distribution in 3D during the actual treatment. Moreover, depending on the actual method used, no additional time for a pretreatment measurement is needed, which is very efficient in the clinical workflow [5]. It has been shown that *in vivo* dosimetry using an electronic portal imaging device (EPID) is an effective QC tool to detect errors [6–9] and this method has been clinically applied for various treatment sites [10].

Radiation treatments of prostate cancer can be performed by using an endorectal balloon. When such a balloon is inserted and inflated with air, the lateral and posterior rectal walls are pushed away from the high-dose region with the aim to reduce rectal toxicity [11,12]. For EPID-based *in vivo* dosimetry this air-filled balloon is a potential problem, because large density inhomogeneities are not accurately handled by the implemented simple back-projection algorithm [13–15].

This inhomogeneity problem has been addressed for EPID dose

verification of lung cancer treatments by the *in aqua vivo* method [15]. “*In aqua*” means that before dose reconstruction the measured images are first converted to a situation as if the patient consisted entirely of water and then the dose comparison is made to a planned dose distribution that is also calculated in the “water-filled patient”. In this study we demonstrate that the *in aqua vivo* method can also be applied to the EPID-based *in vivo* dose verification of prostate cancer radiation treatments when an air-filled endorectal balloon is used.

2. Materials and methods

Ten clinical prostate cancer radiation treatments were investigated. All patients participated in the phase 2 multicenter hypo-FLAME study (hypofractionated Focal Lesion Ablative Microboost in prostate Cancer, NCT02853110). In this study patients with intermediate or high risk prostate cancer were treated with a stereotactic body radiotherapy (SBRT) technique with $5 \times 7 \text{ Gy} = 35 \text{ Gy}$ to the prostate in 5 weekly fractions and an additional simultaneously integrated focal boost to the tumor nodule(s) visible on multiparametric MRI up to $5 \times 10 \text{ Gy} = 50 \text{ Gy}$. As for conventionally fractionated prostate cancer treatments at our institution, an endorectal balloon was used to spare part of the rectal wall [11,12].

Treatment planning was done in Pinnacle (version 9.10/16.0, Philips, Fitchburg, WI, USA) using auto-planning with two 10 MV photon VMAT arcs from $+126^\circ$ to -126° and vice versa over the ventral side of the patient. Because during the course of treatment of these patients the version and the dose modelling in the treatment

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planning system (TPS) were changed, all dose distributions were recalculated in version 16.0 with the newest dose model for consistency in this study.

Before treatment, the plans were verified with a pretreatment measurement with a Delta4 phantom (ScandiDos, Uppsala, Sweden). All plans used in this study fulfilled our chosen pretreatment γ criterion, i.e. 95% of the measured points within the 50% isodose surface were within 3% and 3 mm of the planned dose distribution. As reference dose for the 50% and 3% relative dose values the maximum planned dose in the phantom was used.

All patients were treated on an Elekta Agility linear accelerator (Elekta, Crawley, UK). After position verification with cone-beam computed tomography (CBCT) and correction for translational errors, the patients were treated and EPID *in vivo* dose measurements were performed simultaneously (3 to 5 fractions per patient were measured). 3D *in vivo* EPID dosimetry was done with iViewDose (Elekta, Crawley, UK) which is the commercial implementation of the back-projection algorithm and methods published before [13–15].

For each patient, the *in vivo* dose distributions were first reconstructed using the conventional EPID dosimetry algorithm and compared to the dose distribution of the clinical plan. Secondly, the *in aqua vivo* dose distributions were reconstructed using the *in aqua vivo* method and compared to the dose distribution of the *in aqua vivo* plan, i.e. the plan with a density override equal to 1 on the whole CT dataset. For the comparison a γ evaluation with criteria of 3% and 3 mm was performed for the total fraction dose, i.e. the sum of both arcs. The percentage of points in agreement ($P_{\gamma \leq 1}$) and the mean γ (γ_{mean}) within the 50% isodose surface were calculated for each measured *in vivo* fraction and then averaged per patient, yielding the average values $\bar{P}_{\gamma \leq 1}$ and $\bar{\gamma}_{\text{mean}}$, respectively. For clinical acceptance in this study $\bar{P}_{\gamma \leq 1}$ must be at least 95%. As reference dose for the 50% and 3% relative dose values the maximum planned dose is used in the iViewDose software.

3. Results

The average percentage of points in agreement ($\bar{P}_{\gamma \leq 1}$) of every patient was for the conventional *in vivo* method outside of our clinical acceptance criteria of 95% and improved into clinical acceptance by using the *in aqua vivo* method. Also the average mean γ ($\bar{\gamma}_{\text{mean}}$) improved for every patient when instead of the conventional *in vivo* method the *in aqua vivo* method was used (see Table 1). The disagreement between the dose from the TPS and the EPID-reconstructed dose in the region of the endorectal balloon can clearly be seen in the γ analysis for the

Table 1

γ evaluation for the conventional *in vivo* and the *in aqua vivo* method. $\bar{P}_{\gamma \leq 1}$ is the average per patient of the percentage of points with $\gamma \leq 1$ within the 50% isodose surface. $\bar{\gamma}_{\text{mean}}$ is the average per patient of the mean γ value within the 50% isodose surface. Also mean and standard deviation of the patient averages are listed.

Patient number	Number of measured <i>in vivo</i> fractions	conventional <i>in vivo</i>		<i>in aqua vivo</i>	
		$\bar{P}_{\gamma \leq 1}$	$\bar{\gamma}_{\text{mean}}$	$\bar{P}_{\gamma \leq 1}$	$\bar{\gamma}_{\text{mean}}$
1	4	93.4	0.43	97.7	0.36
2	4	90.7	0.46	98.9	0.34
3	4	89.7	0.46	99.4	0.34
4	3	88.4	0.56	97.1	0.38
5	5	87.9	0.60	99.7	0.35
6	3	92.7	0.43	99.8	0.29
7	5	88.5	0.52	99.5	0.31
8	5	94.2	0.43	98.4	0.37
9	5	94.4	0.41	99.9	0.31
10	4	89.1	0.52	100.0	0.29
mean		90.9	0.48	99.0	0.33
standard deviation		2.5	0.06	1.0	0.03

conventional *in vivo* method (see Fig. 1, one fraction of an example patient). This is due to the large density inhomogeneity caused by the endorectal balloon; the agreement improved considerably, when the *in aqua vivo* method was used.

Overall (averaged over fractions and patients) the percentage of points in agreement improved from $90.9\% \pm 2.5\%$ (1SD) for the conventional *in vivo* method to $99.0\% \pm 1.0\%$ (1SD) for the *in aqua vivo* method; the mean γ improved from 0.48 ± 0.06 (1SD) to 0.33 ± 0.03 (1SD). For both $\bar{P}_{\gamma \leq 1}$ and $\bar{\gamma}_{\text{mean}}$ the difference between the conventional *in vivo* and the *in aqua vivo* method was statistically significant ($p < 0.05$, two-sided paired Student's *t*-test).

The maximum dose calculated with the TPS (see the maximum dose scale value in Fig. 1) for the *in aqua vivo* situation was slightly higher than for the inhomogeneous situation. The density override equal to 1 on the whole CT dataset decreased the density of the pelvic bones which decreased the attenuation of the beams and hence increased the dose. The density override at the position of the endorectal balloon had less effect because the VMAT arcs ran over the ventral side of the patient.

4. Discussion

In this study we performed EPID-based *in vivo* dose verification of prostate cancer treatments with an endorectal balloon. When a simple back-projection method was used, the 10 investigated treatment plans did not meet the clinical γ criteria (note that all plans passed the pretreatment verification and that the patient position was verified with CBCT just prior to treatment). The disagreement is due to the large density inhomogeneity caused by the endorectal balloon and the way it is handled by the back-projection algorithm. We demonstrated that the agreement between the planned and the measured dose distributions improved significantly by using the *in aqua vivo* method instead of the conventional *in vivo* method. To the best of our knowledge, EPID-based *in vivo* dose verification for radiation treatments of prostate cancer with the application an endorectal balloon has not been published before.

In our clinic prostate cancer radiotherapy is performed with an endorectal balloon to spare part of the rectal wall. Moreover, the use of this balloon reduces the intrafraction prostate motion which might be in particular beneficial for longer treatment sessions such as hypofractionated radiotherapy [16] as in the hypo-FLAME study. Monitoring hypofractionated treatments as part of the patient-specific QC is highly desirable due to the impact an error can have when the total dose is given in just a few fractions [17]. *In vivo* EPID dosimetry is a very effective tool for patient-specific QC. Compared to pretreatment verification it has a higher error detectability [9] and is more time efficient. With *in vivo* dosimetry errors with dosimetric consequences can be detected during the actual treatment, such as changes of the patient geometry or changes of the linear accelerator performance [7,15].

The use of the endorectal balloon introduces a (large) density inhomogeneity close to the target volume being the reason that the treatment verification results with the conventional *in vivo* method of the simple back-projection algorithm were outside of our clinical acceptance criteria. The *in aqua vivo* method has been described to be a solution for treatment sites with large density inhomogeneities, such as in lung, esophagus, breast, thoracic wall [10,15]. This study showed that the method is also applicable to other air cavities – here even an artificially introduced one. Note that with the *in aqua vivo* method the dose is reconstructed as if the patient consisted entirely of water and that the reference dose distribution calculated with the TPS also corresponds to the “water-filled patient”. Nevertheless, also with this method, the overall effect of patient geometry, accelerator performance, and data transfer on the dose delivery is measured during the actual patient treatment [15]. Although the intrafraction motion is reduced by the use of the balloon [16], motion of the balloon during treatment would essentially be seen as an anatomy change: the

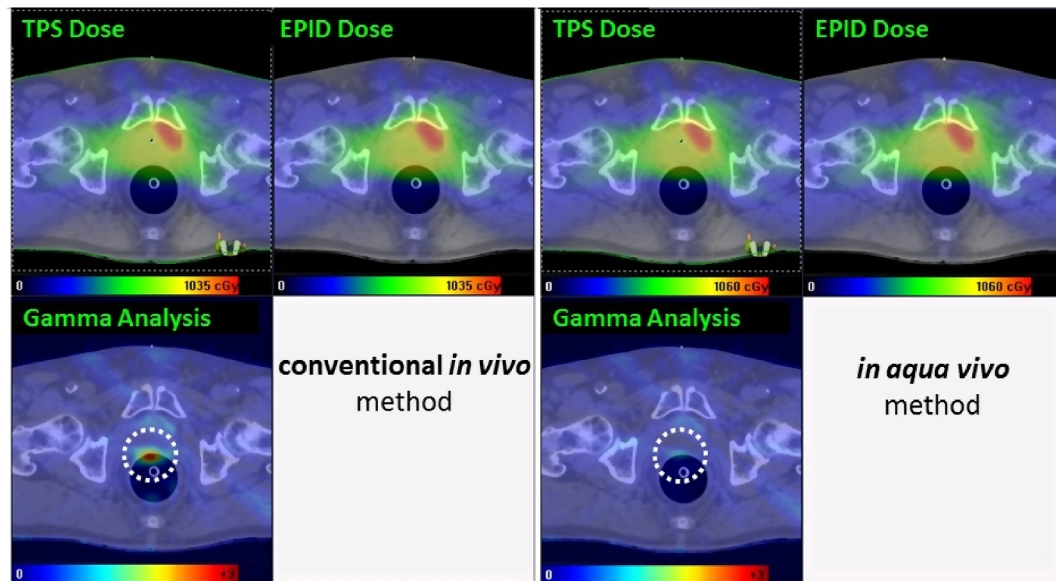


Fig. 1. The dose from the treatment planning system (TPS Dose), the EPID-reconstructed dose (EPID Dose) and the γ analysis (Gamma Analysis) are shown for both the conventional *in vivo* method and for the *in aqua vivo* method for one fraction of patient 6 (see Table 1). The white dotted circle indicates the region with a large disagreement for the conventional method that is improved when the *in aqua vivo* method is used. Note that the results are displayed on the original CT scan, hence the applied density override in the *in aqua vivo* method is not visible.

measured transmission image would change because the inhomogeneity would be at a different location and the *in aqua vivo* method would lead to a different dose than in the reference situation calculated with the TPS. So if the balloon motion would have a dosimetric consequence exceeding the used γ criteria, the method would detect it.

In conclusion, we demonstrated that EPID-based dose verification with a simple back-projection algorithm can be used for *in vivo* dose verification of prostate cancer treatments with an endorectal balloon. The *in aqua vivo* method proved to be a practical solution for the density inhomogeneity problem caused by the endorectal balloon.

Declaration of Competing Interests

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: M. Wendling shares in royalties from a software license agreement for iViewDose between his former employer (The Netherlands Cancer Institute, Amsterdam, The Netherlands) and the manufacturer (Elekta, Crawley, UK).

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