Technical Note

**In vivo dosimetry with an electronic portal imaging device for prostate cancer radiotherapy with an endorectal balloon**

Bo Sterckx, Isabell Steinseifer, Markus Wendling

Department of Radiation Oncology, Radboud university medical center, Nijmegen, the Netherlands

**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% ± 2.5% (1SD) for the conventional **in vivo** method to 99.0% ± 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]. **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 prostateE 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 $-126^\circ$ and vice versa over the ventral side of the patient. Because during the course of treatment these patients the version and the dose modelling in the treatment...
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 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 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 (Pγ ≤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 Pγ ≤1 and γ mean, respectively. For clinical acceptance in this study Pγ ≤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 (Pγ ≤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 (γ 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 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% ± 2.5% (1SD) for the conventional in vivo method to 99.0% ± 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 Pγ ≤1 and γ 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

| Patient number | Number of measured fractions | mainland in vivo | in aqua vivo | Pγ ≤1 | γ 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           | 4                           | 90.9            | 0.48         | 99.0  | 0.33   |
| standard deviation |                  | 2.5             | 0.06         | 1.0   | 0.03   |
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 proofed 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).

References

[1] The Royal College of Radiologists, Society and College of Radiographers, Institute of Physics and Engineering in Medicine, National Patient Safety Agency, British Institute of Radiology. Towards safer radiotherapy. London: The Royal College of Radiologists; 2008.

[2] Izzell GA, Galvin JM, Low D, Palta JR, Rosen I, Sharpe MB, et al. Guidance document on delivery, treatment planning, and clinical implementation of IMRT: report of the IMRT subcommittee of the AAPM radiation therapy committee. Med Phys 2003;30:2089–115.

[3] Palta JR, Liu C, Li JG. Quality assurance of intensity-modulated radiation therapy. Int J Radiat Oncol Biol Phys 2008;71(1 Suppl):S108–12.

[4] Mans A, Schuring D, Arends MP, Vugts CA, Woltman JW, Lotz HT, et al. The NCS code of practice for the quality assurance and control for volumetric modulated arc therapy. Phys Med Biol 2016;61:7221–35.

[5] Mijnheer B, editor. Clinical 3D dosimetry in modern radiation therapy. Boca Raton: CRC Press; 2017.

[6] van Eijl M, McDermott L, Nijsten S, Wendling M, Lambin P, Mijnheer B. A literature review of electronic portal imaging for radiotherapy dosimetry. Radiother Oncol 2008;88:289–309.

[7] Mans A, Wendling M, McDermott LN, Sonke JJ, Tielenburg R, Vlijmi R, et al. Catching errors with in vivo EPID dosimetry. Med Phys 2010;37:2638–44.

[8] Ford EC, Terezakis S, Sournas A, Harris R, Gay H, Mutic S. Quality control quantification (QCQ): A tool to measure the value of quality control checks in radiation oncology. Int J Radiat Oncol Biol Phys 2012;84:e263–9.

[9] Bojchik C, Phillips M, Kael A, Ford E. A quantification of the effectiveness of EPID dosimetry and software-based plan verification systems in detecting incidents in radiotherapy. Med Phys 2015;42:5363–9.

[10] Mijnheer B, Goncalo P, Olaciregui-Ruiz I, Roenendaal RA, van Herk M, Mans A. Overview of 3-year experience with large-scale electronic portal imaging device—based 3-dimensional transit dosimetry. Pract Radiat Oncol 2015;5:e679–87.

[11] van Lin EN, Kristinsson J, Philipsen ME, de Jong DJ, van der Vlag LP, Kuinders JJH, et al. Reduced late rectal mucosal changes after prostate three-dimensional conformal radiotherapy with endorectal balloon as observed in repeated endoscopy. Int J Radiat Oncol Biol Phys 2007;67:799–811.

[12] Kroll R, McColl GM, Hopman WPM, Smeenk RJ. Anal and rectal function after intensity-modulated prostate radiotherapy with endorectal balloon. Radiother Oncol 2018;128:364–8.

[13] Wendling M, McDermott LN, Mans A, Sonke JJ, van Herk M, Mijnheer B. A simple backprojection algorithm for 3D in vivo EPID dosimetry of IMRT treatments. Med Phys 2009;36:3310–21.

[14] Mans A, Remijepr B, Olaciregui-Ruiz I, Wendling M, Sonke JJ, Mijnheer B, et al. 3D dosimetric verification of volumetric-modulated arc therapy by portal dosimetry. Radiother Oncol 2010;94:181–7.

[15] Wendling M, McDermott LN, Mans A, Olaciregui-Ruiz I, Pecharrionagalego R, Sonke JJ, et al. In aqua vivo EPID dosimetry. Med Phys 2012;39:367–77.

[16] Smeenk RJ, Louwe RJ, Langen KM, Shah AF, Kopelian PA, van Lin EN, et al. An endorectal balloon reduces intrafraction prostate motion during radiotherapy. Int J Radiat Oncol Biol Phys 2012;83:661–9.

[17] Yorke E, Gelblum D, Ford E. Patient safety in external beam radiation therapy. AJR Am J Roentgenol 2011;196:768–72.

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.