Radiotherapy and Oncology 118 (2016) 148–153

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

Prostate cancer

In vivo rectal wall measurements during HDR prostate brachytherapy with MOSkin dosimeters integrated on a trans-rectal US probe: Comparison with planned and reconstructed doses

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ARTICLE INFO

Article history:
Received 29 May 2015
Received in revised form 22 December 2015
Accepted 27 December 2015
Available online 12 January 2016

Keywords:
In vivo dosimetry
HDR brachytherapy
Prostate
MOSFET

ABSTRACT

Background and purpose: To study if MOSkin detectors coupled to a trans-rectal ultrasound (TRUS) probe may be used for *in vivo* dosimetry on the rectal wall surface during US-based HDR prostate brachytherapy and to quantify possible discrepancies between planned and delivered doses.
Materials and methods: MOSkins are a specific type of MOSFET dosimeter optimized to measure dose in steep dose gradients on interfaces. Two MOSkins were assembled on a TRUS probe used for on-line treatment planning. Measurements of the dose to the rectal wall were performed over 18 treatment sessions and compared to the doses calculated on the pre-treatment plan (D_{PRE}) and reconstructed on post-treatment images (D_{POST}).
Results: Averages of the absolute differences between MOSkin readings and D_{PRE}, MOSkin readings and D_{POST} and D_{PRE} and D_{POST} were 6.7 ± 5.1%, 3.6 ± 1.9% and 6.3 ± 4.7%, respectively. Agreement between measurements and D_{POST} was significantly better than between measurements and D_{PRE} ($p = 0.002$) and D_{PRE} and D_{POST} ($p = 0.004$). Discrepancy between D_{POST} and D_{PRE} correlated with the time required for treatment planning.
Conclusion: MOSkin dosimeters integrated to the TRUS probe proved to be an accurate instrument for measuring the dose delivered to the rectal wall in HDR prostate brachytherapy. The delivered doses may differ significantly from those calculated in the treatment plan.
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Trans-rectal ultrasound (TRUS) based planning in high dose rate (HDR) prostate brachytherapy (BT) using temporary Ir-192 implants is a well established procedure that produces a highly conformal treatment to the target. The main advantages of this treatment modality are that the prostate gland is usually clearly delineable on ultrasound images and that implant and treatment are usually performed in the same venue without the need of moving the patient [1].

Needle insertion, planning and treatment are performed over a short period of time with the treatment plan showing ideally a representation of the actual delivered dose. In reality, even over this short time lapse, the quality of treatment delivery may be influenced by possible patient movement and internal anatomy alteration [2]. Moreover, potential human inaccuracies or errors may lead to a significant degradation of the plan [3] and are in some cases not recognizable in the treatment planning phase. Since the complexity of BT delivery has rapidly increased and new highly fractionation schemes (i.e., 26–27 Gy in two fractions or 19–21 Gy in one single fraction) have recently been introduced [4], the interest for rigorous quality assurance (QA) procedures to be implemented for independent treatment verification has significantly increased [2,5].

In vivo dosimetry (IVD) represents a potential QA tool, not only for avoiding treatment misadministration by interrupting and verifying the treatment if abnormally high doses are detected, but also for verifying that the delivered dose distributions agree within acceptable limits to the planned distributions. Among the

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http://dx.doi.org/10.1016/j.radonc.2015.12.022
0167-8140/

systems that were developed and already clinically tested for IVD in HDR prostate BT, an important role has been played by passively integrating TLD detectors [6,7] and active methods based on diodes [8], optical fiber-coupled plastic scintillators [9] and MOSFETs [10].

Among MOSFETs, MO*Skin* dosimeters, developed by the Centre for Medical Radiation Physics (CMRP), University of Wollongong, have demonstrated potential for their application to IVD in HDR BT [11–13]. In particular, a novel prototype of TRUS probe with two integrated MO*Skin* dosimeters was recently proposed with the aim of achieving both imaging and real-time IVD with the use of just one single instrument. A preliminary study performed in a gel phantom mimicking a typical prostate implant resulted in an excellent agreement between measurements and calculated data, with an average discrepancy of $-0.6\% \pm 2.6\%$, encouraging *in vivo* clinical application of the proposed method [14].

The purpose of the present study was to use the TRUS-probe with integrated MO*Skin* detectors to perform rectal wall IVD on a set of patients treated with HDR prostate BT. Measured doses with MO*Skin* detectors were compared to dose distributions calculated both on pre-treatment images and on images acquired right after the end of treatment delivery.

Materials and method

Patient and treatment characteristics

12 patients with clinically localized prostate cancer who underwent HDR BT at the Fondazione IRCCS Istituto Nazionale dei Tumori were recruited for this study between October 2013 and February 2015. A total of 18 treatment sessions were investigated. Mean and median ages of the patients were of 70 and 69, respectively. Low and "favorable" intermediate risk patients underwent HDR BT as a monotherapy to the prostate, with 28 Gy in two fractions separated by approximately 3 weeks (i.e., 14 Gy per fraction) [15]. "Unfavorable" intermediate and high risk patients underwent one single fraction of 14 Gy, followed by intensity modulated radiation therapy to the prostate, seminal vesicles and lymphnodes (i.e. 50 Gy in 2 Gy fractions). Classification was given according to the National Comprehensive Cancer Network guidelines [16].

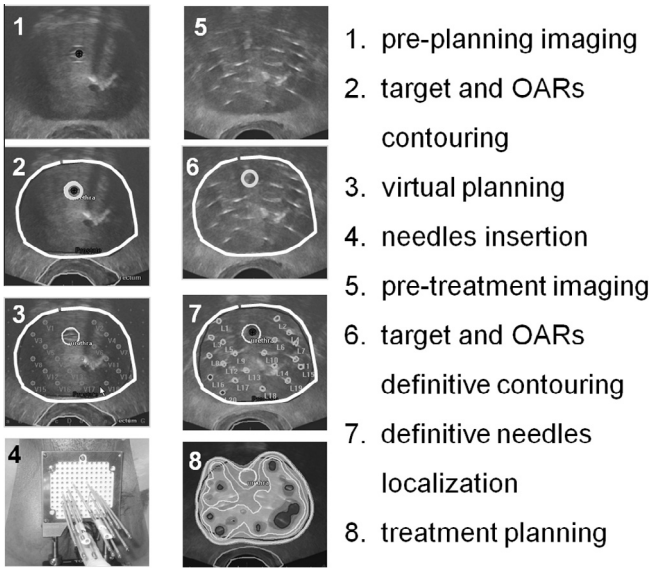

Fig. 1. Outline of the TRUS-guided real-time planning procedure in HDR prostate BT.

US-guided HDR prostate brachytherapy

The main steps of the US-guided treatment planning procedure are illustrated in Fig. 1. A more comprehensive description may be found elsewhere [17].

The prostate gland was considered the PTV without adding any planning margins to the CTV. The drawn organs at risk (OARs) were the intraprostatic urethra extended 10 mm in the caudal direction, the section of the bladder adjacent to the target volume and the anterior rectal wall, extended 10 mm both cranially and caudally from base and apex planes of the prostate. A transurethral Foley catheter was used to better visualize the urethra and to reproduce the filling of the bladder in various phases of the treatment. 3D dose optimization was performed by means of the intraoperative planning system Oncentra Prostate ver. 3.3 (Nucletron Elekta, Veenendaal, The Netherlands) using an inverse based approach. Before pre-treatment imaging, the free length of the needles (OncoSmart Proguide, 2 mm diameter) (i.e., their length in front of the template) was measured to determine their depth inside the patient. Irradiations were performed immediately following treatment planning with a Nucletron microSelectron–HDR remote afterloader device (Nucletron Elekta, Veenendaal, The Netherlands) utilizing a Ir-192 source.

MOSkin dosimeters and the dual purpose probe for imaging and IVD

MO*Skins* are a specific type of MOSFET dosimeter originally developed by the CMRP to measure dose at air-skin interfaces at a reproducible water equivalent depth 0.07 mm as required for skin dosimetry. Their sensitive volume, defined by the volume of the gate oxide, is very small compared to many other detectors (i.e. 4.8×10^{-6} mm^3), which is ideal for point dose measurements in high dose gradient regions [18]. Furthermore, the whole MO*Skin* assembly dimension (3 mm wide, 0.4 mm thick and 330 mm long) allows the positioning of the detector in clinically relevant regions, normally difficult to be reached without extra invasive procedures. For real time *in vivo* dosimetry, the MO*Skin* dosimeters are connected to a dedicated computerized battery operated readout system. In this study, two MO*Skin* dosimeters were integrated onto a TRUS probe (BK Medical Systems, Herlev, Denmark) to constitute a dual purpose probe (DPP), as shown in Fig. 2, and as previously studied in phantom by Tenconi, et al. [14]. The dosimeters were placed at $x_1 = 25 \pm 0.5$ mm and $x_2 = 35 \pm 0.5$ mm from the transversal transducer to not produce artifacts on the transversal images. A 2 mm thick silicone layer was placed between the dosimeters and the probe to attenuate backscattered electrons produced by the interaction of the source radiation and the high Z materials within the probe [19].

MOSkin calibration

Dosimeter calibration was performed with an Ir-192 HDR source, removing MO*Skins* from the TRUS probe and placing them in a phantom (Plastic Water DT, CIRS, Norfolk, VA) at a source-to-detector distance of 21 ± 0.1 mm, in accordance to a calibration procedure described elsewhere [12]. For each detector, irradiations were repeated five times and each calibration factor N was determined as $N = D_{cal}/V_{mean}$ (given in cGy/mV), where V_{mean} was the resulting average values of the measured threshold voltage shifts. The reference dose data D_{cal} were those resulting from the treatment planning system (TPS) and cross-checked with an independent software based on the AAPM TG-43 algorithm, in accordance to several other studies reported in the literature [13,20,21]. Factors implemented in the TPS are those tabulated in Daskalov et al. [22] and are obtained by means of Monte Carlo photon transport code knowing the characteristics of the specific source model