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Online *in vivo* dosimetry in high dose rate prostate brchytherapy with MO*Skin* detectors: In phantom feasibility study

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HIGHLIGHTS

- A needles implant was set-up in phantom to simulate prostate brachytherapy treatments.
- *In vivo* dosimetry was performed in the urethral catheter with MO*Skin* dosimeters.
- Dual-MO*Skin* detectors resulted to be accurate dosimeters to perform this task.

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ABSTRACT

MO*Skin* detectors were studied to perform real-time *in vivo* dose measurements in high dose rate prostate brachytherapy. Measurements were performed inside an urethral catheter in a gel phantom simulating a real prostate implant. Measured and expected doses were compared and the discrepancy was found to be within 8.9% and 3.8% for single MO*Skin* and dual-MO*Skin* configurations, respectively. Results show that dual-MO*Skin* detectors can be profitably adopted in prostate brachytherapy treatments to perform real-time *in vivo* dosimetry inside the urethra.

1. Introduction

1.1. *In vivo dosimetry in radiotherapy*

The recent developments of more sophisticated radiotherapy and brachytherapy (BT) techniques call for the improvement of instruments and methodologies employed for the quality control of the performed treatments. Due to the achievable high conformity of modern BT associated with steep dose gradients, a careful verification of the accuracy in the delivered dose distributions, as planned by the Treatment Planning System (TPS) through mathematical models, is gaining importance.

In vivo dosimetry is a reliable method to compare planned and delivered dose distributions, representing therefore a valid tool to systematically verify treatment accuracy and improve radiotherapy quality control (Lambert et al., 2007; Mijnheer, 2008). Particularly advantageous for *in vivo* dosimetry are detectors that allow online dose reading. These dosimeters provide in fact real-time measurements during treatment, avoiding therapy misadministration and allowing at the same time intraoperative dose re-planning for treatment error correction.

Current methods for *in vivo* dosimetry are mainly based on the application of thermoluminescence detectors (TLDs) (Toye et al., 2009) or semiconductor diodes (Waldhäusl et al., 2005). TLDs involve offline process providing the integral dose absorbed during patient treatment and require special procedures in order to achieve good precision of the results. On the other hand, diodes show rapid processing time, high sensitivity and immediate reuse, however, they show a high energy dependence and the delivered dose is therefore not promptly inferred from the diode reading. Moreover, the major disadvantages of diodes are their relative large sizes, which make them unable to be held in many catheters placed inside the patient to perform *in vivo* dosimetry.

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New detectors such as fiber optic coupled scintillation dosimeters (Suchowerska et al., 2007; Therriault-Proulx et al., 2011) and metal oxide semiconductor field effect transistors (MOSFETs) (Zilio et al., 2006; Fagerstrom et al., 2008) have recently been introduced to perform *in vivo* dosimetry. In particular, MOSFETs show many advantages, such as good spatial resolution, high sensitivity, real-time read-out without deterioration of information, negligible radiation field perturbation owing to their small size and ease of use. In particular, great interest was dedicated to the application of MOSFETs to BT, because the typical large dose gradients achieved in BT necessitate a small detector with a reduced active volume for accurate dosimetry. In this work, a specific type of MOSFET dosimeter called "MO*Skin*" which was developed by the Center for Medical Radiation Physics (CMRP) of the University of Wollongong (Australia) (Qi et al., 2007; Kwan et al., 2008, 2009) has been studied.

1.2. High dose rate prostate brachytherapy

High dose rate (HDR) prostate BT allows the delivery of local and high conformal dose directly into the tumor, minimizing exposure of the surrounding healthy tissues. Due to the large dose delivered to the target in a single fraction and the dose constraints to be simultaneously satisfied for organs at risk, it is very important to have as small as possible discrepancy between planned and delivered dose. The development and application of reliable and accurate methods for monitoring the dose delivered to critical organs is therefore crucial.

Among these organs at risk, the urethra is most likely susceptible to acute and/or late toxicity resulting from the treatment (i.e. urethritis, stenosis), as it is inside the target volume (Fig. 1a). However, its localization for treatment planning purposes is particularly difficult due to images artefacts generated by the presence of source catheters, especially if transrectal ultrasound imaging is performed. Moreover, source catheters are themselves difficult to be accurately localized on the same images and therefore calculated dose distributions are susceptible to inaccuracies (Fig. 1b). The real-time dosimetry in the urethra is therefore very important and will be supplementary to reinforce existing QA programs.

Studies aimed at characterizing the dosimetric properties of MO*Skin* dosimeters have already demonstrated that they are promising instruments for performing *in vivo* dosimetry during HDR BT treatments (Qi et al., 2007, 2012; Kwan et al., 2008). Measurements finalized to detect the accuracy of the dosimeters and the change in sensitivity as a function of depth and angle of incidence of the radiation, have already shown good agreement between MO*Skin* response and dose calculated by the TPS (Hardcastle et al., 2010). Aim of this work was to study and develop the applicability of the MO*Skin* dosimeters for urethral dose measurement in prostate HDR BT.

2. Materials and method

2.1. MOSkin dosimetry system

The design of this particular type of MOSFET is optimized to measure dose in steep dose gradients. Different from other commercial MOSFETs, MO*Skin* die is embedded in a thin kapton layer and hermetically sealed with water-equivalent flexible carrier of reproducible thickness and avoid traditional wire bonding with high –Z wires. The sensitive volume, defined by the volume of the gate oxide, is 4.8×10^{-6} mm^3. MO*Skin* detectors can be adopted alone or coupled in a face-to-face arrangement. This face-to-face dual-MO*Skin* arrangement is referred to in this text as the "dual-MO*Skin*". The dual-MO*Skin*, proposed and developed at CMRP, allows for angular-independent measurements as it compensates the naturally asymmetrical structure of the MOSFET chip relative to the beam direction (Hardcastle et al., 2010). The dosimetry system adopted with MO*Skin* detectors includes a microprocessor based reader which is connected to a laptop provided with a dedicated software ("MosPlot"). The computer data acquisition system measures periodically the instantaneous voltage signal with a user defined frequency. The "MosPlot" software allows for the online graphical representation of the change in the threshold voltage (proportional to accumulated dose) or increments in the threshold voltage for consecutive readouts (proportional to dose rate).

2.2. Nucletron microselectron-HDR brachytherapy facility

BT irradiations were performed using a Microselectron-HDR (Nucletron, Veenendaal, the Netherlands) high dose rate remote afterloading device. The facility is provided with a ^{192}Ir radioactive source which has an active length of 3.6 mm and a diameter of 0.65 mm. The source is sealed inside a capsule that is welded to one end of a flexible steel cable and the treatment unit moves it to the required dwell positions.

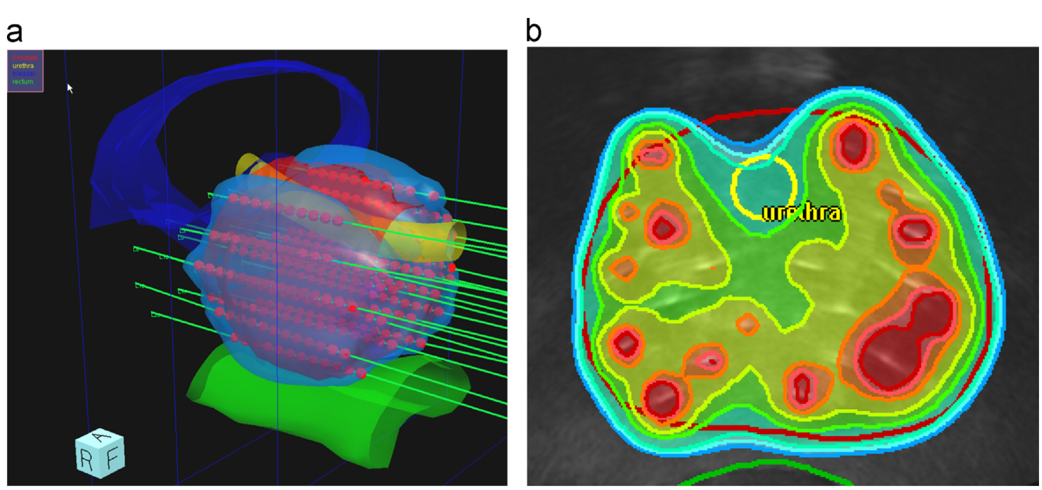

Fig. 1. (a) 3D graphical representation of an HDR brachytherapy plan of the prostate (dark red). Urethra, rectum and bladder are represented in yellow, green and blue, respectively. Source catheters are drawn as green lines, source dwell positions are represented by red spheres and resulting dose distribution (95% isodose) is given in light blue; (b) transversal prostate image with the resulting dose distribution. Characteristic hot spots are present around some of the implanted needles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)