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TRUS-probe integrated MOSkin detectors for rectal wall *in vivo* dosimetry in HDR brachytherapy: In phantom feasibility study

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HIGHLIGHTS

- MOS*kins* were placed on a TRUS probe to perform rectal wall *in vivo* dosimetry.
- Their response was studied in a gel phantom including a typical prostate implant.
- The average discrepancy between calculated and measured dose was −0.6 ± 2.6%.

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ABSTRACT

The increasing complexity and high amount of dose per fraction delivered in prostate high dose rate (HDR) brachytherapy treatments call for the implementation of accurate and effective methods for the systematic and independent quality control of the overall treatment procedure. In this study, MOS*kin* detectors were placed on a trans-rectal ultrasound (TRUS) probe with the aim of performing both imaging and real time rectal wall *in vivo* dosimetry with the use of just one single instrument. After an adequate calibration of the detectors, which was carried out in a solid water phantom, the use of MOS*kins* integrated to the TRUS probe was studied in a gel phantom with a typical (simplified) prostate implant. Measured and calculated doses from the treatment planning system were compared, with a resulting very low average discrepancy of −0.6 ± 2.6%. The results are very promising and of particular clinical importance, however, further *in vivo* investigation is planned to validate the proposed method.

1. Introduction

Brachytherapy (BT) delivers an extremely conformed high dose to the prostate, using either a low dose rate or a high dose rate (HDR) technique (Morton and Hoskin, 2013). With HDR, a single high activity source of short-range radiation (e.g., Ir-192) is remotely moved to predefined positions via temporarily needles that are implanted within the target. By adjusting the source dwell times in each one of the planned dwell positions, a tailored and customized dose distribution can be achieved to ensure optimal coverage of the defined treatment volume.

Nevertheless, HDR BT is a meticulous technique and procedural variations caused by factors such as patient motion, needle movements, anatomical changes occurring between imaging and treatments, as well as potential human inaccuracies or errors, may lead to a significant degradation of the plan (Thomadsen et al., 2003). Therefore, to ensure the delivered dose agrees within acceptable limits to that planned, rigorous quality assurance (QA) procedures should be implemented for independent treatment verification. In particular, effective and accurate QA methods need to be developed, as the complexity of BT delivery has rapidly increased (Palmer et al., 2012; Tanderup et al., 2013) and new highly fractionation schemes (i.e., 26–27 Gy in two fraction or 19–21 Gy in one single fraction) have recently been introduced (Morton and Hoskin, 2013).

In vivo dosimetry represents a useful QA tool, not only for avoiding treatment misadministration, but also for evaluating

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doses to organs at risk (i.e., urethra, rectum and bladder). Moreover, if performed on-line, it allows the constant monitoring of the dose delivered during the treatment, enabling the immediate intervention of the clinician if adverse dose readings are detected (Lambert et al., 2007).

A number of different systems to perform *in vivo* dosimetry have been developed, including passive integrating thermoluminescent dosimeters (TLDs) and active methods based on diodes, diamond detectors, optical fiber-coupled scintillators and MOSFETs (Fagerstrom et al., 2008; Rustgi, 1998; Toye et al., 2009; Waldhäusl et al., 2005; Zilio et al., 2006). Some of these have already been used to perform *in vivo* prostate dosimetry by directly placing them in either a needle in the prostate, a catheter in the urethra or in the rectum (Seymour et al., 2011; Suchowerska et al., 2011). As the trans-rectal ultrasound (TRUS) probe is one possible means of performing real time prostate HDR BT treatment planning, it would be advantageous to include dosimeters to the probe so that the probe itself would represent a tool for both imaging and *in vivo* rectal wall dosimetry. This system would in fact be particularly convenient, avoiding the insertion of extra invasive catheters or needles for the positioning of the detectors. In this study, a particular type of MOSFET dosimeters, MOS*kins*, were integrated to the TRUS probe, with phantom measurements of prostate brachytherapy implants performed.

2. Materials and method

2.1. MOSkin dosimeters and the brachytherapy facility

MOS*kin* detectors are particular type of MOSFET devices recently developed by the Centre for Medical Radiation Physics (CMRP), University of Wollongong, Australia. They are characterized by their novel packaging technology used to seal the sensor chip, which differentiates them from other commercial MOSFETs and makes them more suitable for dose measurements in steep dose gradients and for skin dosimetry. Their sensitive volume, defined by the volume of the gate oxide, is 4.8×10^{-6} mm^3. More specific information about MOS*kin* dosimeters may be found elsewhere (Qi et al., 2007; Kwan et al., 2009).

All the measurements in this study were carried out with a microSelectron-HDR remote afterloader device (Nucletron, Veenendaal, The Netherlands) provided with an Ir-192 source with active length of 3.6 mm and diameter of 0.65 mm. The source is contained in a stainless steel capsule, laser welded to a steel cable for its remote positioning at required locations into the treatment catheters/needles.

2.2. MOSkin calibration with the Ir-192 brachytherapy source

MOS*kin* detectors calibrations were performed in a water-equivalent phantom constructed with several solid water slabs of various thickness placed in a stacked configuration to provide adequate backscatter conditions. One MOS*kin* at a time was positioned at the center of the phantom and was oriented with its sensitive volume in source direction.

A plastic needle for source positioning was inserted in the phantom with its centre at a distance of 21 ± 0.1 mm from the MOS*kin* detector. To irradiate the detector, a single source dwell position was chosen right above the MOS*kin* (i.e., nearest point of the source catheter to the dosimeter) (Fig. 1). In order to ensure that the response uncertainty associated with the MOS*kin* reader (±1 mV) was less than 1% of the threshold voltage change, a dwell time of 78s was chosen. Each detector was irradiated three times and the corresponding voltage threshold measurements V_i were recorded and averaged to V_{mean}. The delivered dose at the calibration position D_{cal} was then calculated by a means of a commercial BT treatment planning system (TPS) (Oncentra Prostate, Nucletron, The Netherlands) which complies with the American Association of Physicists in Medicine (AAPM) TG-43 dose calculation formalism (Rivard et al., 2004). The calibration factor, N, was determined as $N = D_{cal}/V_{mean}$, given in cGy/mV.

2.3. Transrectal ultrasound-based prostate HDR brachytherapy

Prostate ultrasound imaging by means of a TRUS probe is one of the possible image guidance modalities used to both guide the insertion of needles through the perineum and plan HDR BT treatments. Its use instead of CT imaging is constantly increasing (Batchelar et al., 2013). It would therefore be particularly convenient and effective to attach accurate dosimeters to the TRUS-probe in order to perform both imaging and real time rectal wall *in vivo* dosimetry by the use of just one single instrument.

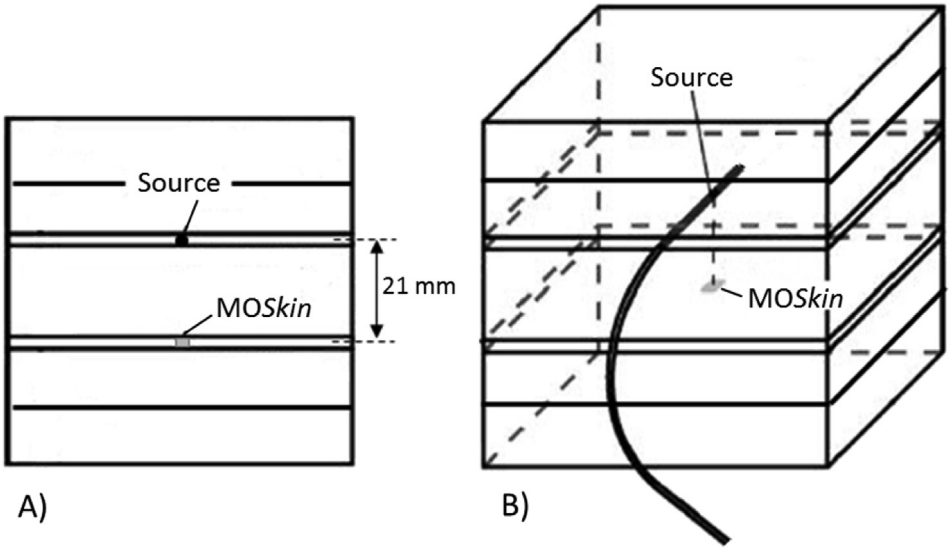

Fig. 1. Schematics of the experimental setup. A) The MOS*kin* detector was placed in the centre of the water-equivalent phantom. The orthogonal distance to the source catheter was of 21 mm. B) During irradiation, the single dwell position of the Ir-192 source was chosen in correspondence to the closest distance to the MOS*kin* detector (i.e., 21 mm).