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Real-time measurement of urethral dose and position during permanent seed implantation for prostate brachytherapy

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ABSTRACT

PURPOSE: The *in vivo* dosimetry tool, RADPOS, has been modified to include a metal oxide–silicon semiconductor field effect transistor (MOSFET) array with an electromagnetic positioning sensor. This allows dose monitoring at five points rather than just at single dose point as in the other versions of the device. The detector has been used in a clinical trial, which is the first to measure both urethral dose and internal motion concurrently during permanent seed implantation for prostate brachytherapy using a single probe.

METHODS AND MATERIALS: The RADPOS detector was secured inside a Foley catheter inside the patient's urethra. Spatial coordinates of the RADPOS detector were read every 0.5 s, and the timing of events such as needle insertion was noted. The MOSFET readings were taken over two 10-min periods; once all seeds had been implanted both before and after the transrectal ultrasound (TRUS), the probe was removed. Measurements were completed for 16 patients.

RESULTS: Maximum integral dose in the prostatic urethral ranged from 89 to 195 Gy, and dose varied from −66% to 36% depending on the rectal probe position. The change in position of the RADPOS sensor owing to the removal of the TRUS probe ranged from 1.4 to 9.7 mm.

CONCLUSIONS: The modified RADPOS detector with MOSFET array is able to provide real-time dose information, which can be used to monitor dose rates while implantation is performed and to estimate the total integrated dose. Changes in position including those owing to the TRUS probe can be significant and should be quantified to evaluate the influence on dose distributions.

Keywords: Brachytherapy; Prostate motion; Electromagnetic positioning system; MOSFET; RADPOS

Introduction

There are several treatment options for patients diagnosed with localized prostate cancer including radical prostatectomy, active surveillance, hormonal therapy, external beam radiation therapy, and brachytherapy (1). One brachytherapy technique commonly used is transperineal interstitial permanent prostate brachytherapy (TIPPB). This technique involves treating the tumor with radiation from radioactive seeds that are permanently placed inside the prostate. This allows for higher intraprostatic doses that are achievable with external beam radiation therapy and also has the convenience of a single-day outpatient procedure (2). Ultrasound images acquired with a transrectal ultrasound (TRUS) probe are used to guide the placement of needles throughout the procedure. It is a common practice for the patient to have a followup computed tomography (CT) scan 1 month after implantation to assess the position of the seeds at that time and to evaluate deviations from the planned dose distribution. Delivered dose to the target volume and nearby organs at risk can deviate from planned values due to uncertainties in needle placement and seed migration (3). These factors can lead to inadequate dose coverage of the target or to compromised sparing of organs at risk. Dose to the urethra, bladder, and rectum are of particular concern due to the organs' proximity to the prostate.

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Swelling and movement of the prostate are also significant problems because such changes can affect internal anatomy and dose distribution by making it difficult to place the seeds in the desired preplanned positions. Prostate motion during external beam radiation therapy has been widely studied (4–11); however, measured data from TIPPB procedures are much less common. For external beam treatments, the source of radiation is outside the body; therefore, the effect of prostate motion is clear. As the prostate shifts within the body, its position relative to the radiation treatment field changes. This can cause a partial geographic miss or harmful irradiation of sensitive tissues. For brachytherapy, the radiation sources are placed within the prostate itself, so the effect of motion on the planned dose distribution is less predictable because the frame of reference is different than that for external beam treatments. Changes in prostate position and shape can alter the position of the seeds relative to the organs at risk. Deformations can also cause changes in coverage to the target volume as prostate tissue contracts or expands. Motion and deformation of the prostate during implantation have been quantified using axial ultrasound images, and a median change of 1.5 cm (ranging from 0.0 to 3.0 cm) in the base position of the prostate was reported (12). The same study also found a median deformation of 6.8 mm and median displacement of 1.9 mm in the $x-y$ (transverse) plane (12). A recent study investigating seed movement owing to the removal of the TRUS probe identified three specific patterns of seed motion, namely anterior–posterior extension, superior–inferior and lateral contraction, and anterior translation of lateral seeds (13). The anterior–posterior movement of seeds was the largest effect on the order of 2–3 mm. It was concluded that this was because of the posterior translation of the prostate coordinate system owing to the release of pressure along the posterior wall caused by the probe. The dosimetric effect of the measured seed motion was not determined but was identified as future work for the group (13). Simultaneous measurement of changes in position and dose can provide valuable insight into the effect of translation and extension of seeds on the intended dose distribution.

Although seeds cannot be removed once they are in place, *in vivo* dosimetry is useful to identify patients who may be at an increased risk for complications because of higher than expected dose values (14). Real-time *in vivo* dosimetry has the added potential of providing feedback during the implant procedure regarding whether the dose rate is approaching threshold values and revisions to placement of subsequent seeds are needed (15). It can also signal when an underdosage of the target volume might occur, allowing the physician to add more seeds if necessary. The use of metal oxide–silicon semiconductor field effect transistors (MOSFETs) for *in vivo* dose measurements inside the urethra has been limited. A feasibility study first used a single high-sensitivity micro-MOSFET inside a Foley catheter during permanent implant procedures and moved it in increments of 1 cm along the urethra to characterize the dose rate at various points for 5 patients (14). Maximum urethral dose rates for different patients ranged from 0.1 to 0.16 Gy/h, which corresponded to a total absorbed dose that ranged from 205 to 328 Gy. Another group collected similar readings using a high-sensitivity linear MOSFET array with five individual MOSFET dosimeters in 29 patients (16). Data were collected for 1 h while the patients were in postoperative recovery and compared with dose rates calculated from the postimplant CT scan. Measured dose rates ranged from 0.073 to 0.199 Gy/h depending on the location of each MOSFET. These values correspond to a total absorbed dose that ranged from 150 to 409 Gy. The differences between individual MOSFET dose measurements and calculated treatment plan (TP) dose rates ranged from 0% to 25.3%, and the overall correlation between the two sets of values was 0.992 (16). These studies demonstrated the feasibility of using MOSFET linear arrays for evaluation of initial dose rate to the prostate and urethra after implantation.

A method for monitoring urethral dose during the implant procedure has been developed elsewhere to evaluate planned seed distribution (15). A MOSFET array was placed in the urethral catheter as described previously, and measurements were taken during seed implantation. For the latter half of implantation, measurements were used to calculate the urethral dose rate, which was compared with the maximum tolerable dose rate. Based on the measurements and potential impact on prostate coverage, placement of subsequent needles was reconsidered. Measurements taken during the implant procedure, with the TRUS probe in place, were also compared with those taken postoperatively, with the TRUS probe removed. Good agreement was found indicating that the presence of the ultrasound probe and resulting changes to internal anatomy did not disturb measured dose inside the urethra in this patient group.

The new *in vivo* dosimetry tool, RADPOS, was developed in Ottawa and combines MOSFET dosimetry with an electromagnetic positioning sensor for simultaneous measurement in real time of dose and spatial position (17). The RADPOS system has Health Canada approval and is commercially available through Best Medical (Ottawa, ON, Canada). The first prototype of the device contained one MOSFET dosimeter per position monitor, which allowed for measurement of both dose and position at a single point. Multiple detectors could be used simultaneously to record dose and position information for various points on a patient's body. This version of the device has been used in a study that tracked surface dose and breathing motion over the course of treatment for patients undergoing external beam treatments for lung cancer (17, 18). A new version of the RADPOS device has recently been made by modifying the original design to include a MOSFET array rather than a single MOSFET. This allows for simultaneous dose monitoring at five different points along the detector axis.