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In vivo dosimetry in gynecological applications—A feasibility study

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ABSTRACT

PURPOSE: To investigate the feasibility of in vivo dosimetry using microMOSFET dosimeters in patients treated with brachytherapy using two types of gynecological applicators.

METHODS AND MATERIALS: In this study, a microMOSFET was placed in an empty needle of an Utrecht Interstitial Fletcher applicator or MUPIT (Martinez Universal Perineal Interstitial Template) applicator for independent verification of treatment delivery. Measurements were performed in 10 patients, with one to three microMOSFETs per applicator and repeated for one to four fractions, resulting in 50 in vivo measurements. Phantom measurements were used to determine characteristics of the microMOSFETs.

RESULTS: Phantom measurements showed a linear relationship between dose and microMOSFET threshold voltage, and a calibration coefficient (mV/cGy) was determined. Reproducibility of repeated 50 cGy irradiations was 2% (1 standard deviation). Distance and angle dependencies were measured and correction factors were determined. Subsequently, three microMOSFETs were placed in a phantom to measure a validation plan. The difference between predicted and measured dose was less than the measurement uncertainty (±9%, 2 standard deviations). In vivo measurements were corrected for distance and angle dependencies. Differences between predicted and measured dose in the patients were smaller than the measurement uncertainty for the majority of the measurements.

CONCLUSIONS: In vivo dosimetry using microMOSFETs in MUPIT and Utrecht Interstitial Fletcher applicators has proved to be feasible. Reimaging should be performed after detection of differences larger than 10% between predicted and measured dose to verify the applicator configuration. Movement of the applicator relative to the target or organs at risk is undetectable with this method.

Keywords: In vivo dosimetry; Brachytherapy; Gynecological; microMOSFET; Feasibility study

Introduction

Pretreatment imaging with CT and/or MRI is currently standard practice in gynecological brachytherapy (1, 2). Using 3D imaging, the position of the applicator in relation to the tumor and the organs at risk (OARs) can be accurately determined, enabling individual treatment planning. However, imaging during treatment is still rare and verification of delivered dose remains uncommon. Therefore, the exact position of the applicator during treatment is unknown which may result in incorrect dose delivery. In addition, due to the large number of manual steps in brachytherapy treatment delivery (e.g., selection of the treatment plan and connection of the transfer tubes to the applicator), the risk of human errors is high (3, 4).

To verify correct dose delivery during treatment, in vivo dosimetry in brachytherapy has been investigated in several studies (5–7). Tanderup et al. (8) discussed the available detectors and dosimetry systems which could be used for in vivo dosimetry and found that MOSFETs (Metal Oxide Semiconductor Field Effect Transistor detector) are suitable for in vivo dosimetry due to their small size and commercial availability. The limited operating life and energy dependency of the MOSFET are potential downsides.

Several studies describe the use of MOSFETs to determine the dose in OAR (5, 6, 9, 10), and the uncertainty

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of the position of the MOSFET is reported as a serious disadvantage. Haughey et al. (10) concluded that MOSFETs are not suitable for in vivo dosimetry in rectum for high-dose-rate (HDR) brachytherapy due to calibration drift, angular dependence, and position uncertainty of the MOSFET. In contrast, Qi et al. (9) conclude that MOSFETs are reliable for quality assurance of HDR brachytherapy when characteristics and correction factors for angle and distance dependency are determined before use.

In the studies described in the previous paragraph, the MOSFETs were placed intraluminally in OAR (5, 6, 10) or in a phantom (9) to perform the measurements. Only one published study describes in vivo measurements in HDR brachytherapy with a MOSFET placed in the applicator (11). The authors used a home-made applicator for the treatment of a nasopharyngeal carcinoma.

In our study, we assessed the feasibility for clinical use of MOSFETs for in vivo dosimetry in interstitial gynecological HDR brachytherapy to detect deformations of the applicator or misconnection of the channels. We started with determination of the characteristics of the MOSFET. Subsequently, we determined a set of correction factors for the distance and angle dependencies of the MOSFET and checked those factors in a validation plan. Finally, we performed in vivo measurements in gynecological brachytherapy by placing MOSFETs in empty needles of the applicator.

Methods

Measurement equipment

The phantoms used to perform the measurements are described in Appendix A. Clinical and validation treatment plans were made in the Flexiplan planning system (Elekta AB, Stockholm, Sweden) and delivered using the Flexitron afterloader (Elekta AB, Stockholm, Sweden).

The microMOSFET (TN-502RDM, Best Medical Canada, Ottawa, Ontario, Canada) was used in combination with a bias supply (TN-RD-22, Best Medical Canada) and a reader (TN-502RD, Best Medical Canada). The bias supply setting was set to high sensitivity mode and the measured threshold voltage was displayed on the reader. This measurement equipment is only suitable for total dose measurements.

Calibration of microMOSFET

A polystyrene phantom (Fig. A.1) was used for dose calibration of the microMOSFETs. The distance between the microMOSFET and the source was set to 3 cm. At closer distances, the changes in the energy spectrum of the Iridium-192 source and the dose rate are too large for reliable measurements (12−14). The microMOSFET was irradiated with a polar angle of 90° and an azimuthal angle of 180° (see Fig. B.1 for the definition of the coordinate system). The predefined dose delivered at the microMOSFET was 50 cGy. The calibration coefficient C_{cal} describes the relationship between dose and threshold voltage increase and was determined for each microMOSFET. The calibration procedure of a microMOSFET can be performed within 15 minutes, including set up and clearing, and each separate measurement takes less than 1 min.

Correction for measured dose

According to Qi et al. (9), measured MOSFET signal can be translated to absorbed dose using distance and angle-dependent correction factors. Assuming the correction factors are independent of each other, the corrected measured dose by the microMOSFET D_i per source position i can be calculated with the formula

$$D_i(d_i,\theta_i,\varphi_i)=\frac{M_i * C_i(d_i,\theta_i,\varphi_i)}{C_{cal}}$$

with d_i the distance between source and microMOSFET, θ_i, and ϕ_i, respectively, the azimuthal and polar angle between source and microMOSFET, M_i the difference in threshold voltage before and after irradiation, C_{cal} the calibration factor of the microMOSFET at the time of measurement, and

$$C_i(d_i,\theta_i,\varphi_i)=C_{distance}(d_i)*C_{angle,azim}(\theta_i)*C_{angle,polar}(\varphi_i)$$

For clinical and validation treatment plans, the measured voltage is a summation of the contribution over all dwell positions, each with different distance and angle with respect to the measurement position. Assuming for total dose $D_{tot} = M * C_{tot}/C_{cal}$, $D_{tot} = \sum D_i(d_i, \theta_i, \Phi_i)$ and $M = \sum M_i$, a total correction factor (C_{tot}) can be calculated with the formula

$$C_{tot}=\frac{\sum_i D_i(d_i,\theta_i,\varphi_i)}{\sum_i \frac{D_i(d_i,\theta_i,\varphi_i)}{C_i(d_i,\theta_i,\varphi_i)}}$$

Determination of microMOSFET characteristics

Table 1 lists the measurement settings to determine the characteristics of the microMOSFET. All measurements were performed at least three times, without replacing the microMOSFET, to reduce measurement uncertainty.

Reproducibility of microMOSFET response across dose levels was assessed by performing repeated irradiations while keeping the dose constant. This also allowed us to verify the linear relation between dose and threshold voltage increase.

The energy spectrum of the Ir-192 source changes with the radial distance, due to beam hardening in material. The microMOSFET response is itself energy dependent (13−15) and will therefore be influenced by its distance to the source. Therefore, we introduced a correction factor