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Dependency of semiconductor dosimeter responses, used in MDR/LDR brachytherapy, on factors which are important in clinical conditions

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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Summary

Aim Dependence of diode dosimeters on variation of temperature, distance, dose rate and incident beam angle for MDR/LDR intracavitary brachytherapy was investigated.

Materials/Methods Flexible probes from PTW/Germany were irradiated using Cs-137 sources. The rectum probe (type 9112) had five semiconductors and the bladder probe had one. Firstly, detectors' dependence on temperature was studied. The probes were immersed into a water tank and the temperature was slowly increased. To investigate the angular dependence of the diodes, the sources were placed at 5cm distance from diodes at four different angles. Probes were placed at 3cm distance from the centre of the source arrays and the responses for three different dose rates were evaluated. To assess the dependency of responses on distance, probes were placed at three different distances with constant dose rate.

Results A slight linear increase of the diode signal with temperature was found. The diodes exhibited a variation in sensitivity with dose rate less than 0.15% and with distance less than 0.04% per mm. A linear decrease of the diode responses was also observed with increase of the radiation beam angle.

Conclusions The current study showed that there is no significant variation in the response of diodes with temperature, dose rate and distance for MDR brachytherapy. However, the increase of radiation beam angle led to a significant decrease of diode response. In conclusion, the observed temperature, dose rate and distance effects are negligible but the diode correction factor as a function of the incidence beam angle must be applied to these diodes.

Key words **brachytherapy • semiconductor**

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Background

An important aspect of all radiotherapy treatments is the accurate delivery of the prescribed dose [1,2].

There are many steps involved in the dose delivery process in radiotherapy. Each of these steps in treatment planning and execution will contribute to the overall uncertainty in the actual dose delivered. The final accuracy of the delivered dose can only be checked directly by means of *in vivo* dosimetry [3,4]. Therefore, some form of *in vivo* dosimetry is necessary to ensure accuracy and quality control of dose delivery [2].

In vivo dosimetry is either performed with semiconductor diodes or thermoluminescent dosimeters (TLD) [5]. As the use of TLD techniques is time consuming and laborious (which makes them impractical for use on every patient) and because they are passive dosimeters in that their results cannot be obtained immediately, silicon diode detectors have gained popularity as *in vivo* dosimeters. The main advantage of diodes is that measurements can be obtained on-line, which allows an immediate check. Other advantages of diodes include high sensitivity, good spatial resolution, small size, simple instrumentation, no bias voltage, durability, and independence from changes in air pressure [4–11].

Diode *in vivo* dosimetry is a recommended tool for improvement in quality of patient care in radiation therapy[12].

All users of semiconductor *in vivo* dosimetry should, however, be well aware of the rather extensive calibration work which is necessary before using this kind of detector in clinical routine, when very accurate measurements on patients have to be performed [6].

For a diode detector, the correction factors due to temperature, beam incident direction, dose rate, depth, etc, need to be characterized [4,5,7,13,14].

Correction factors account for changes in the diode response when measurement and calibration conditions are different. The corrections made in an individual clinical practice depend on the accuracy desired from *in vivo* dosimetry, the diode system used, and the treatment techniques that will be monitored [15].

Aim

The aim of this study is to characterize an *in vivo* diode dosimetry system for clinical use during MDR brachytherapy.

Materials and Methods

In this study rectum and bladder probes from PTW/Germany were used. The outer diameter of the rectum probe (type 9112) was 7mm with five semiconductors placed 15mm apart in a flexible tube, and the bladder probe (type 9113) had one semiconductor with an outer diameter of 3mm. The diodes were connected to a twelve-channel (PTW/MULTIDOSE) electrometer.

Irradiations were performed with a Selectron LDR/MDR afterloading unit (Nucletron, Netherlands) using Manchester applicators. The unit was equipped with 36 Cs-137 sources with an average apparent activity of 34.9mCi.

In order to study the temperature dependence of the semiconductors, they were immersed into a thermostate-equipped Perspex tank (30×30×30cm) filled with water and the temperature of which was measured with an immersed thermistor. The temperature was slowly increased from 25°C to 35°C in steps of 1°C intervals. A water pump was activated between the measurements to homogenize the water temperature.

The measurements were repeated three times under a constant dose rate of 187.5cGy/h (MDR) at a distance of 3cm from the cylinder applicator. In Figure 1 the bladder and rectum probes are shown. The catheter, which is placed between probes, contains 25 sources to reach the dose rate of 187.5cGy/h.

The average of three measurements performed at the same temperature was taken to establish the correction factor for temperature K_T:

$$K_T = \frac{R(T)}{R(26°C)}$$

where R(26°C) and R(T) are the responses of the diode at 26°C and at temperature T°C, respectively.

To assess the directional dependence of the diodes, measurements were performed at 0°, 30°, 44° and 53° angles at a dose rate of 21.48cGy/h, while the temperature was kept constant at 26°C.

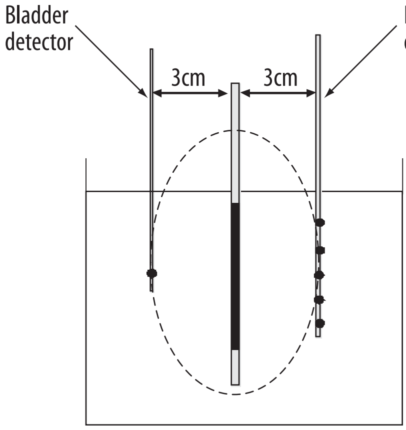

Figure 1. A schematic diagram of the set up for the temperature calibration. Dotted line represents the 100% Isodose surface (Dose rate: 187.5cGy/h).

Five active sources were loaded into the applicator, forming a spherical dose distribution at the radius of 5cm. The probes were proportionally displaced horizontally and the sources displaced vertically to adjust the position and angle of the diodes relative to the position of the sources. Figure 2 demonstrates these displacements for each angle.

The angular diode factor (K_θ) is expressed as:

$$K_\theta = \frac{R(\theta)}{R(\theta{=}0)}$$

where R(θ=0) and R(θ) are the responses of the diode at 0° and at the angle θ, respectively.

To investigate the dependence of the sensitivity of the semiconductor detectors on dose rate bladder and rectum probes were placed at 3cm distance from the centre of the source arrays and the response for three different dose rates (185.6cGy/h, 216.07cGy/h and 235.51cGy/h) were evaluated.

To assess the dependence of the responses of the diodes to distance from the sources, probes were placed at three different distances (3cm, 3.5cm and 3.9cm) at a constant dose rate of (185.2cGy/h). In order to reach the constant dose rate for each distance the arrays of the source were changed. 29, 33 and 35 sources were used for 3, 3.5 and 3.9 cm respectively.

RESULTS

The responses of the diodes show a slight linear increase for the temperature range between 25°C to 35°C. On average, the linear regression of these three measurements was 0.08% per degree Celsius (P-Value=0.069). The effect of temperature on diode response is shown in Figure 3.

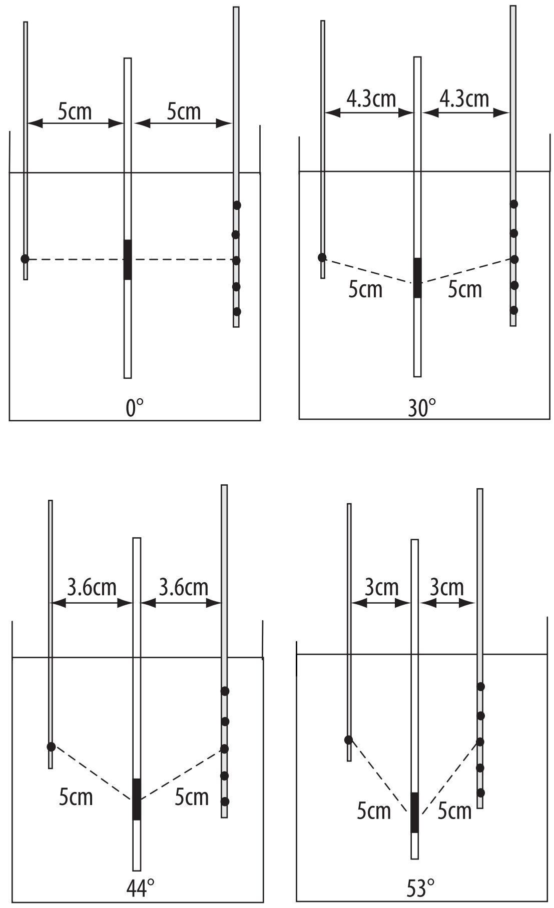

Figure 2. Displacement of detectors to achieve the constant distance (and dose rate) in each angle.

The diode responses show a linear decrease with increasing incidence angle from 0° to 53° (P-Value=0.028). In Figure 4 the results for the bladder and one of the rectum semiconductors are shown.

No significant discrepancy was observed in the response of the diodes to dose rate changes at a constant distance (0.13% per cGy/h) – see Figure 5 (results were normalized to unity at 185.6cGy/h).

Also, no systematic difference was found for measurements at a constant dose rate at different distances (–0.04% per mm) (P-Value=0.66) – see Figure 6.

Table 1 lists the results of all performed measurements.

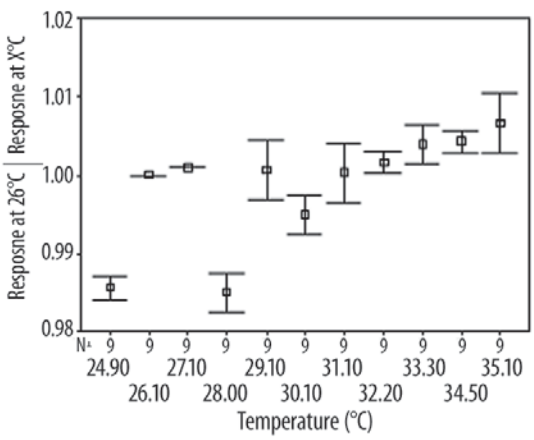

Figure 3. The effect of temperature on diode response.

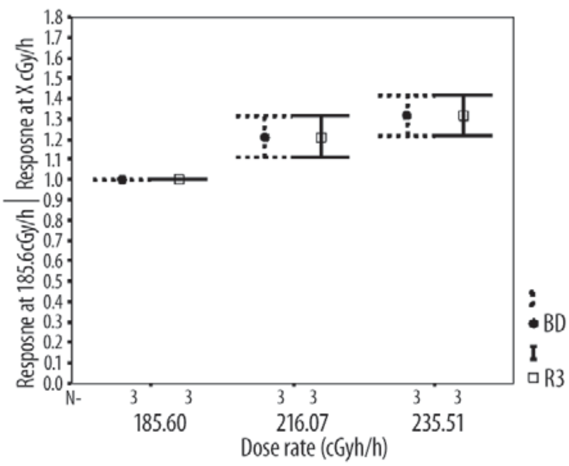

Figure 5. Diode correction factor as a function of the dose rate.

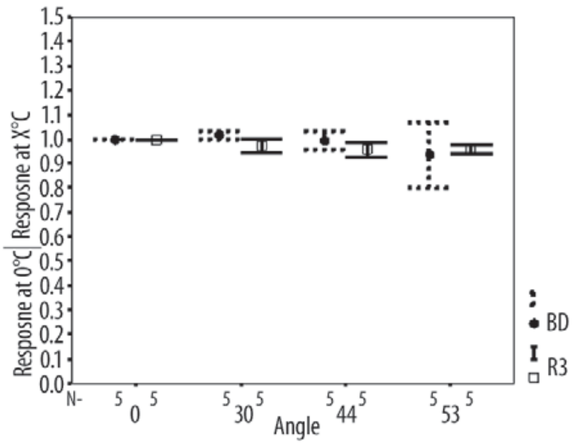

Figure 4. Angular dependence correction factor.

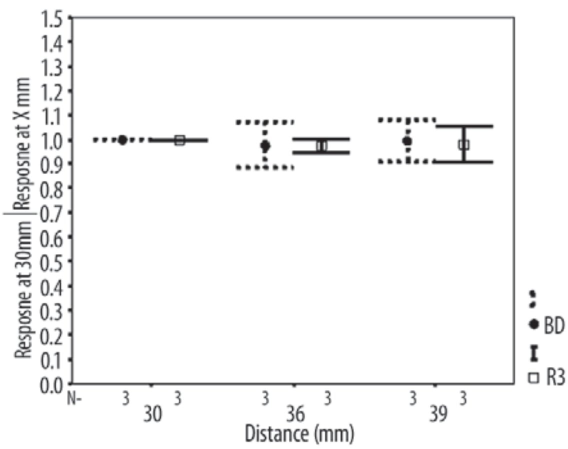

Figure 6. Diode correction factor as a function of the distance.

Table 1. Summary of parameters influencing the diode response based on phantom measurements: the maximum and minimum values, the mean and the standard deviation (1σ) are specified in percentages

Parameter	Range (%)	Mean ± σ (%)
Temperature	0.079 to 0.094	0.08±0.004
Angle	0.035 to 0.13	0.086±0.002
Dose rate	0.11 to 0.15	0.13±0.001
Distance	–0.11 to 0.04	–0.04±0.001

Discussion

Although different types of semiconductors have been fully studied and well characterized, most of these studies are focused on external beam treatments.

The sensitivity variation with temperature of the diode dosimeter agrees with the results obtained by other authors [5–8,10,14], who reported values ranging from 0 to 0.6 per degree Celsius. They characterized temperature dependence of diodes for HDR brachytherapy and external beam therapy.

In external beam treatment it is mentioned that if diodes are left for 1 min on the patient's skin before the irradiation is completed, no correction for temperature variations is necessary [6,8].

For angle dependence in longitudinal direction, Waldhausl et al. [5] reported (for the same type of probes that were used in this study) response variation between –2.0 and +1.8 from the mean value (σ=0.9%).

The increase of diode response as a function of dose rate has also been observed by J. Van Dam et al. [6] and D. Marre et al. [8].

CONCLUSIONS

In the presented study, semiconductor diodes for *in vivo* dosimetry were characterized for MDR brachytherapy. The dependence of the diode response on temperature, angle of incident beam, dose rate and distance was investigated.

Based on our experimental results, we conclude that for these diodes and under these experimental and clinical conditions (MDR brachytherapy) the temperature, dose rate and distance correction factors are negligible, whereas the diode correction factor as a function of the incidence beam angle must be applied to these diodes.

Our results are inconsistent with previously reported measurements for HDR brachytherapy.

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