DIAMETER DISCREPANCY AND TREATMENT ACCURACY IN EXTERNAL BEAM RADIOTHERAPY

by

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One of the most problematic elements of radiation therapy is the determination of contour data or treatment depth which may vary due to various parameters. The provision of this data is crucial for treatment calculations and setup. The present study is devoted to the assessment of discrepancies between the water equivalent (effective) diameter and patient diameter of the dose delivered to the target. Combined entrance and exit dose measurements were carried out on patients treated for thorax, abdomen, and pelvic cancers by ^{60}Co gamma rays, using silicon diodes. The effective diameter and target dose were evaluated on the basis of dose transmission data. Our study reveals that the most influential parameter leading to discrepancies in target dose delivery is the difference between effective depth and patient depth. A difference of more than 5% in the target dose is bound to happen when the difference between the effective and contour diameters is greater than 10%. Therefore, using the effective diameter for treatment calculations provides a more realistic value of the target dose, since it incorporates the impact of all contributing factors.

Key words: external beam radiotherapy, water equivalent depth, in vivo dosimetry, semiconductor diode

INTRODUCTION

An ideal radiotherapeutic procedure would be the one ensuring an exact delivery of a sufficiently high radiation dose to the target volume, while maintaining the dose to the surrounding normal tissue as low as possible. This goal can be attained through a precise therapeutic chain which can only be validated by *in vivo* dosimetry. In addition, *in vivo* dosimetry provides helpful hints for improvement in the quality of patient treatment [1-9]. In this regard, international and national organizations have recommended criteria aimed at achieving certain accuracy and precision standards. According to the international commission on radiation units and measurements (ICRU), treatment uncertainty should be within the 5 percent margin of the dose prescribed in conventional radiotherapy [10]. The proposed margin is adaptable to modern therapeutic techniques, as well [11].

In vivo dosimetry is usually applied to measurements of the entrance, exit and intracavitary doses and the determination of doses delivered to critical organs. The entrance dose serves to check the output and performance of the treatment device, accuracy of patient setups and treatment calculations. In addition, the exit dose value is used to evaluate uncertainties related to patient data, such as contour errors and tissue inhomogeneities, as well as that of the algorithm in the treatment planning system [5].

Radiotherapy involves a number of steps, each of them contributing to the overall uncertainty of the dose delivered to the target volume. One of the most problematic stages of the process is the determination of contour or treatment depth data which vary due to human mistake, body shape, body movements and tissue inhomogeneity. The provision of this data is crucial for treatment calculations and setup. The aim of this study, besides implementing an *in vivo* dosiometric program for the sake of quality control, is the assessment of the role of discrepancies between water equivalent depth and patient depth in the accuracy of targeted dose deliveries.

MATERIALS AND METHODS

In vivo dosimetry has been performed on patients isocentrically treated for thorax, abdomen, and pelvic cancers. The treatment dose was delivered thorough a pair of parallel opposed (POP) anterior-posterior (AP/PA) treatment fields or along two POP lateral (L) fields, as a four-field box technique. Dose measure-

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ments have been carried out in 342 treatment fields of which 214 were in the anterior posterior (AP/PA) and 128 in lateral (L) positions. For each couple of the POP fields, the average dose values were considered as the delivered dose. Patients have been treated by gamma radiation (with an average energy of 1.25 MeV) from a Theratron Phoenix ^{60}Co therapy unit. Entrance and exit doses, defined as the depth of the dose maximum from the entrance and exit surfaces, respectively, have been measured simultaneously during treatment. Measurements have been carried out weekly, as a routine check for each patient treated for thorax, abdomen or pelvic carcinoma, using PTW *in-vivo* Semiconductor Probes, along with a VIVODOS E Four-channel dosimeter. P-type diodes with an effective area of 1 mm^2 and effective detection thickness of 30 μm were used as well, along with 1.0 g/cm^2 of titanium as the buildup material for achieving the required electron equilibrium.

In order to convert the diode signal (in nC) to the dose value (in cGy), a calibration procedure was carried out [12, 13]. Diodes have been calibrated for entrance (D_{en}) and exit dose (D_{ex}) measurements, separately. A standard 30 cm 30 cm 10 cm water phantom was used to simulate the body backscatter during calibration. The diodes were irradiated to identical dose values on the phantom surface under the reference geometry (field size of 10 cm 10 cm and source-skin distance (SSD) of 80 cm) and corresponding signals compared with the respective absolute dose values recorded by a 0.6 cm^3 Guarded Farmer NE 2571 ionization chamber (IC) connected to a Farmer NE 2670A electrometer. The IC was calibrated by the National Secondary Standard Dosimetry Laboratory and positioned inside the phantom at the depth of 5 cm. The IC recorded dose values were then converted to D_{en} and D_{ex}, using the tabulated percent depth dose (PDD) data. The relationship between the diode signal in nC and the dose value indicated by the IC reading in cGy is found to follow a linear function, as presented in fig. 1.

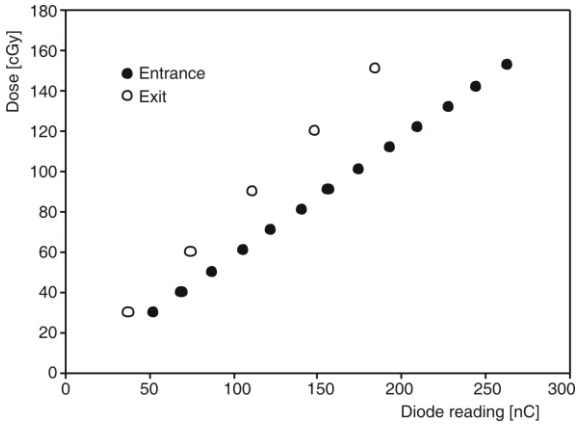

Figure 1. Dose – response function for one of the diodes; the function has been determined for entrance and exit surfaces, separately

Correction factors (CF) have been determined so as to account for the probable differences between clinical and calibration (reference) geometry. For this purpose, the influence of variations in gantry orientation, source-skin distance (SSD) and the field size of the diode response, studied (see figs. 2, 3, and 4). CF has been defined as the ratio of the IC absorbed dose and diode readings in the two geometries [5]

$$CF \frac{\frac{IC\text{ absorbed dose [cGy]}}{R_{\text{diod, clinical geometry}}\text{ [nC]}}}{\frac{IC\text{ absorbed dose [cGy]}}{R_{\text{diod, reference geometry}}\text{ [nC]}}} \quad (1)$$

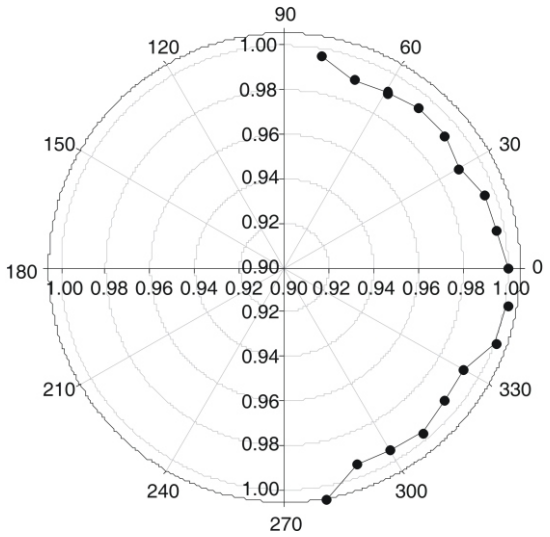

Figure 2. Angle correction factor for one of the diodes

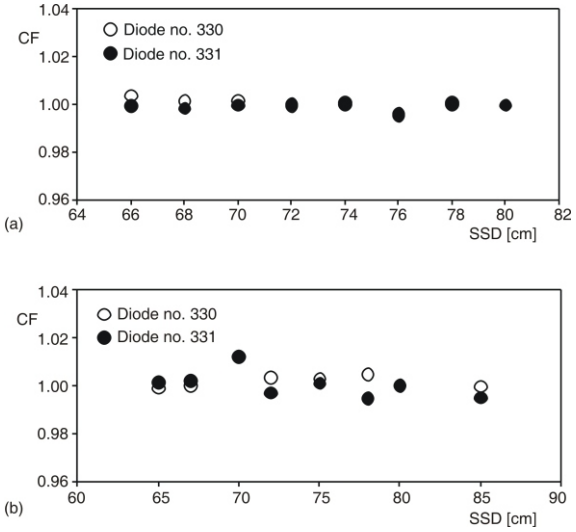

Figure 3. Diode correction factor as a function of the SSD for entrance dose (a), and exit dose measurements (b); all data has been evaluated on a 10 cm 10 cm field size (at the collimator)

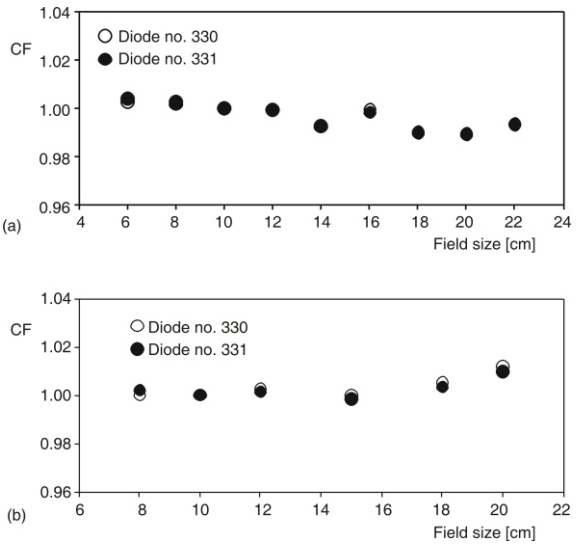

Figure 4. Diode correction factor as a function of the field size for entrance dose (a), and exit dose measurements (b); all data has been evaluated in SSD = 80 cm

The influence of field sizes and SSD variations in diode responses was found to amount to less than 1% and, therefore, negligible.

The influence of the gantry orientation and temperature dependence is considered to be negligible, due to the steady beam axis and rapid readings of the diodes [7]. The dose value is calculated by replacing the diode reading (R) in the determined linear calibration function.

The midline dose is calculated on the basis of transmission measurements. The ratio of the exit dose (D_{ex}) to the entrance dose (D_{en}) is defined as the exit transmission ($T_{ex} = D_{ex}/D_{en}$). Also, the exit and midline transmissions (T_{ex}, T_{mid}) are calculated and established as tables on the basis of the following relations (adopted from [5])

$$T_{ex} \quad TMR(\acute{A}, d_{z\ d_m}) \ \frac{80 \quad Z/2 \quad d_m}{80 \quad Z/2 \quad d_m}^{2} \frac{BSF(\acute{A})}{BSF(A_0)} \quad (2)$$

$$T_{mid} \quad TMR(A, d_{z/2}) \ \frac{80 \quad Z/2 \quad d_m}{80}^{2} \frac{BSF(A)}{BSF(A_0)} \quad (3)$$

where A_0, A, and $\acute{A}$ are the field sizes at the entrance, midline and exit levels. Z – the water equivalent (effective) depth, and d_m – the depth of the maximum dose. *TMR* and *BSF* stand for Tissue Maximum Ratio and the Back Scatter Factor, respectively. The doses delivered to the midline (target) were determined based on the method recommended by Leunens *et al*. [5]:

(1) determination of the exit transmission (T_{ex} = = D_{ex}/D_{en}), using the measured entrance (D_{en}) and exit dose (D_{ex}) values,
(2) determination of water equivalent thickness (Z) for the patient, interpolating the measured T_{ex} in the T_{ex} table composed according to relation (2),
(3) extraction of T_{mid} from the table composed according to relation (3), considering the value of Z evaluated in step 2, and
(4) estimation of the midline absorbed dose through the measured entrance dose (D_{en}) and calculated midline transmission (T_{mid}) through the midline transmission relation ($T_{mid} = D_{mid}/D_{en}$).

As for treatments where the target was not placed exactly at the midline, the given depth (c) was converted to the water equivalent depth (w), through a depth correction factor (f_d) defined as $f_d = Z/d$, d being the patient diameter estimated from the body contour. Upon that, the water equivalent depth was estimated according to: $w = cf_d$.

RESULTS AND DISCUSSION

The results of entrance dose measurements are evaluated as the ratio of the measured ($D_{en,m}$) to the expected ($D_{en,cal}$) dose values ($D_{en,m}/D_{en,cal}$) 100, as presented in fig. 5. They show a rather Gaussian distribution, with a mean value of 103.0% and a standard deviation of 2.5%. At this level, both the entrance dose distribution and the average value show a systematic overdose. The values for AP/PA and L positions are (103.0 2.6)% and (103.0 2.5)%, respectively. Variations of more than 5% have occurred in 17% of the cases. The frequency distributions of the ratio of effective to contour depths (Z/d) are presented in fig. 6. A more skewed Gaussian distribution was found when the mean value amounted to (99.0 7.7)%. AP/PA and L positions with mean values of (98.6 7.9)% and (99.7 7.3)% showed a relatively similar distribution. On the average, a systematic underestimation of the effective depth was detected. In this case, a difference of more than 5% occurred in 21% of the treatment fields, most likely related to contour inaccuracies, body shape, tissue inhomogeneity and body movement.

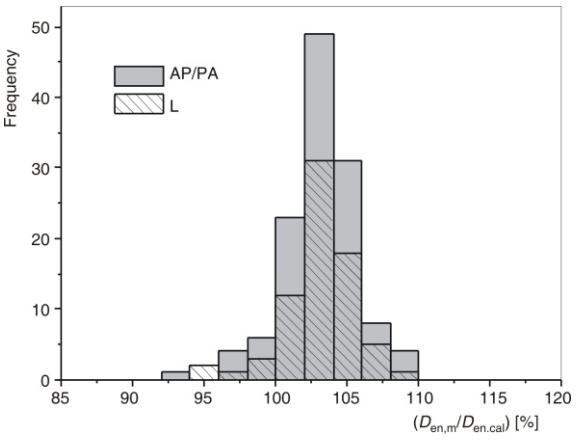

Figure 5. Frequency distribution of the ratio of the measured entrance dose ($D_{en,m}$) to the expected value ($D_{en,cal}$) for AP/PA and L position

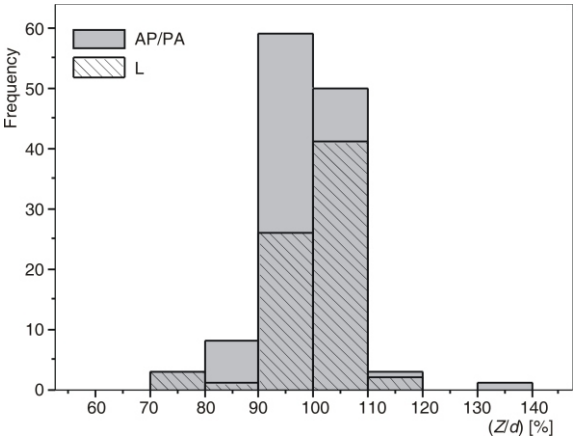

Figure 6. Frequency distribution of the ratio of the effective diameter (*Z*) to the contour diameter (*d*) for AP/PA and L positions

In order to evaluate the contribution of counter inaccuracies (human mistakes), the diameter was randomly checked by a caliper on 48 patients and the discrepancy with contour data determined. The root square of the differences is plotted in fig. 7. For comparison purposes, the root square of the difference between the measured diameter and the effective diameter is also presented as a negative value. Differences between contour and measured depths equal to 1cm or over have been observed in 18.7% of these cases, indicating that diameter measurements are the problematic part of treatment preparation. We have established that patient thickness, especially in the AP/PA position, extends up to 0.5 cm, due to respiration, and that the exact diameter is sometimes hard to determine, due to body contour variations along the treatment field, especially for excessively fat or slim patients. The largest deviation from the effective depth was found in an esophagus lateral field in which the presence of the lung lead to a deviation of almost 4 cm.

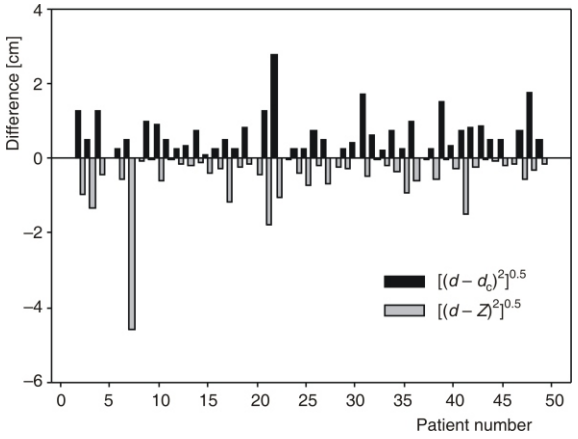

Figure 7. Difference between the patient diameter (*d*) and contour diameter (d_c).; the differences from effective depth (*Z*) are presented as negative values

Figure 8 shows the frequency distribution of the midline dose ratio ($D_{mid,m}/D_{mid,p}$) 100. Similarly to the depth ratio, the midline dose ratio shows a wide Gaussian distribution with a mean value of (102.6 7.2)%. A discrepancy of more than 5% at the midline (target) level was determined in 28.0% of the treatment fields. In 8.9% of them, a difference in the entrance dose, in 66.1% of them between the contour depth and effective depth, in 10.7% a differences in both, while in 14.3% of the fields there were no disparities greater than 5%.

The mean percentage ratio of the midline dose for AP/PA and L Positions was found to amount to (102.8 5.4)% and (102.4 9.6)%, respectively.

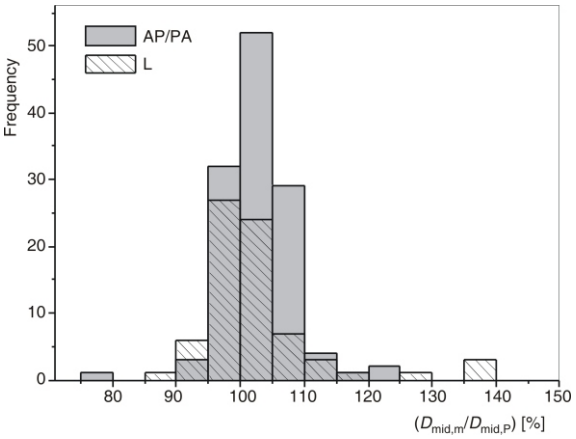

Figure 8. Frequency distribution of the ratio of the evaluated target dose ($D_{mid,m}$) to the prescribed ($D_{mid,p}$) one for AP/PA and L positions

CONCLUSIONS

The overall accuracy of the treatments has been studied by *in vivo* dosimetry, using silicon diodes on patients treated for thorax, abdomen, and pelvic tumors in external beam radiotherapy. Water-equivalent depth and the midline dose have been evaluated using transmission dose data. Though a systematic overdose of approximately 3% at the entrance level was detected, to some extent, this may be attributed to the target itself, but in cases when the target dose inaccuracies exceed 5%, the difference between effective depth and patient depth is the dominant factor. According to our measurements, a difference of more than 5% in the target dose is bound to happen when the difference between the effective and contour diameters is more than 10%. Since dose ratios are used for the determination of the effective diameter, its accuracy is quite independent of treatment precision, which leads to a more comprehensive depth value for treatment calculations. Therefore, the use of the effective diameter for treatment calculation provides a

more realistic value of the target dose since it incorporates the impact of a variety of decisive factors.

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AUTHOR CONTRIBUTIONS

Experiments were carried out by B. Ghanbar Moghaddam under the supervision of M. Vahabi-Moghaddam. Both authors analyzed and discussed the results. The manuscript was written by B. Ghanbar Moghaddam and edited by M. Vahabi-Moghaddam and the figures were prepared by B. Ghanbar Moghaddam.

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УТИЦАЈ НЕСАГЛАСНОСТИ ПРЕЧНИКА НА ТАЧНОСТ ПОСТУПКА ПРИ РАДИОТЕРАПИЈИ СПОЉАШЊИМ СНОПОМ

Један од најзахтевнијих задатака у терапији зрачењем је одређивање контурних података или дубине лечења, који могу да зависе од различитих параметара. Познавање ових података је пресудно за прорачун терапије као и њену поставку. Овај рад је посвећен процени утицаја одступања између еквивалентног (ефективног) пречника у води и пацијентног пречника, при давању дозе. Употребом силицијумских диода извршена су комбинована мерења улазне и излазне дозе на пацијенту током терапије кобалтом грудног коша, абдомена и карлице. На основу података о трансмисији дозе одређени су ефективни пречник и циљана доза. На основу наших истраживања открили смо да је разлика између ефективне дубине и пацијентне дубине најутицајнији параметар који води до одступања у давању дозе. Разлика већа од 5% у датој дози настаје када је разлика између ефективних и контурних пречника већа од 10%. Стога, употреба ефективних пречника за прорачун терапије даје реалније вредности циљане дозе која укључује утицај свих ефективних фактора.

Кључне речи: радиотерапија спољашњим снопом, еквивалентна дубина у води, дозиметрија in vivo, полупроводничка диода