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Diode calibration for dose determination in total body irradiation

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Background: Total Body Irradiation (TBI) is different from standard radiotherapy in many aspects, so it is not easy to predict the delivered dose to the patient under TBI treatment. Diode dosimetry procedures for surface dose reading can help to define variations of the actually delivered dose from the prescribed one. The aim of this study was to describe the measurements made to calibrate diodes in order to implement as a dosimeter for TBI tratment. An algorithm was also proposed based on diode dosimetry in order to determine the midplane dose. **Materials and Methods:** In this study, four p-type diodes connected to a MULTIDOSE electrometer were implemented as dosimeter. For diode calibration a water phantom with dimension of 30×30×32cm^3 along with a 0.6 cc Farmer ion chamber were used. Directional dependence of diodes, the effects of thickness correction factor and complete backscatter factor were studied. Three algorithms, arithmetic, geometric mean and proposed algorithm were used to investigate midplane dose determination in TBI condition. **Results:** It was found by measurements that the effect of angle incident on diode response was significant and should have been taken into account. Variation in thickness correction factor was found about 0.7%. The accuracy in midplane dose determination in the arithmetic, geometric mean and proposed algorithm was about 3.8, 12.5 and 3.3%, respectively. **Conclusion:** Diode dosimetry is very useful as a check of midplane dose delivered to patients under TBI treatment. When the calibration and correction factors are carefully determined, high precision can be obtained. The proposed algorithm by this study seems to be useful in order to midplane dose determination in TBI condition. **Iran. J. Radiat. Res., 2008; 6 (1): 43-50**

Keywords: *Diode calibration, total body irradiation.*

INTRODUCTION

Total body irradiation (TBI) differs in many aspects from standard irradiation procedures, since the whole body including the skin is the target volume, so, it is difficult to predict the actual dose delivered to the patients under TBI treatment [(1)]. In spite of this difference, the accuracy in the determination of an administrated dose in TBI, as well as, standard radiotherapy has to be high (preferably below ±5%). In this presentation the type of the detectors used, and the procedure of their calibration are considered as important conditions in the whole chain of dose determination procedure [(2)].

In recent years the use of diode dosimeters has become very common in the practice of radiation therapy. Early researches concentrated on understanding the intrinsic physical characteristics of p-type silicon diodes and determining how the diodes can be applied to accelerator or ^{60}Co beam dosimetry. Diodes were shown to be useful for scanning beam symmetry, flatness profiles and measuring percentage depth dose curves [(1)]. Several investigators have presented methods for measuring entrance and exit doses with diode detectors in order to determine midplane dose [(2-6)]. Diodes were implemented to replace the TLD because they provide immediate results, and labor intense TLD often depend on operator skills [(1)].

The primary aim of this work was to present how diodes could be implemented as dosimeters for TBI and to evaluate the methods of determination midplane dose in patients irradiated by ^{60}Co for TBI.

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MATERIALS AND METHODS

Materials

TBI was performed using the ^{60}Co beam (Teratron 780-C, Canada). Customized cerrebend lung blocks witch allowed partial transmission were being used to assure a maximum lung dose of 10±0.5 Gy. The collimator was opened to its maximum field size which was 35×35 cm^2 at the isocenter and was rotated 45 degree [7]. The source-skin distance was set to 250 cm [4]. A TBI stand was interposed which consisted 11 steel pieces with dimensions of 70×100×210 cm^3 with two purposes: first, to hold the lung shield, and second, to support the patient.

A three dimensional, anthromorphic phantom was used to determine midplane dose. The phantom had been developed using natural human bone, paraffin, sodium chlorides as the equivalent tissue [8].

Four semiconductor diodes (T60010L P-type, PTW-Freiburg, Germany) connected to the MULTIDOSE electrometer (T10004, PTW-Freiburg, Germany) were used. Each diode had a build up cap of titanium (0.1 gr/cm^2), stated to be equivalent for 1-5 MV photon energies. All calibration measurements were performed with a water phantom (30×30×32 cm^3) [9]. A 0.6cc Farmer chamber (TM30010, PTW-Freiburg, Germany) connected to a UNIDOS electrometer (TM10001, PTW-Freiburg, Germany) was used as the reference detector. A 0.3cc ionization chamber (TM31013, PTW-Freiburg, Germany) was also inserted in the anthromorphic phantom to check accuracy in midplane dose determination.

Methods

Calibration procedure: Calibration means the determination of the calibration factors of each diode and the determination of the correction factors which are required to calculate the absorbed dose when measuring (clinical) and calibrating conditions differences [10]. Since TBI is different from other technique, calibration on this situation is not so easy; therefore, the calibration situation will be similar to clinical situation.

In order to determine the measured dose with the diode, the following equation was used:

$$\text{dose (D)} = \text{diode reading (M)} \times F_{cal} \times F_{corr} \quad (1)$$

The calibration factor of each diode was determined in TBI reference conditions (SSD= 250 cm, field size= 35×35 cm^2 at isocenter and gantry 90 degree, collimator 45 degree).

For entrance calibration, the diodes were placed on the front surface of the water phantom forming a circle of diameter centered on the beam axis (to avoid shadow effect). The 0.6cc Farmer chamber was placed at the depth of maximum dose (5mm) at the beam axis (figure 1.a). Then the signal of each diode was compared to the absorbed dose determined with the ionization chamber. By definition calibration factor is the ratio of the absorbed dose measured with the ionization chamber (D) and the diode reading (M) as below:

$$F_{cal} = \frac{\text{absorbed dose (D) (measured with chamber)}}{\text{diode reading (M) (measured with diode)}} \quad (2)$$

For exit calibration water phantom was turned to 180 degree (figure 1.b) and the process was repeated as earlier mentioned [4, 10].

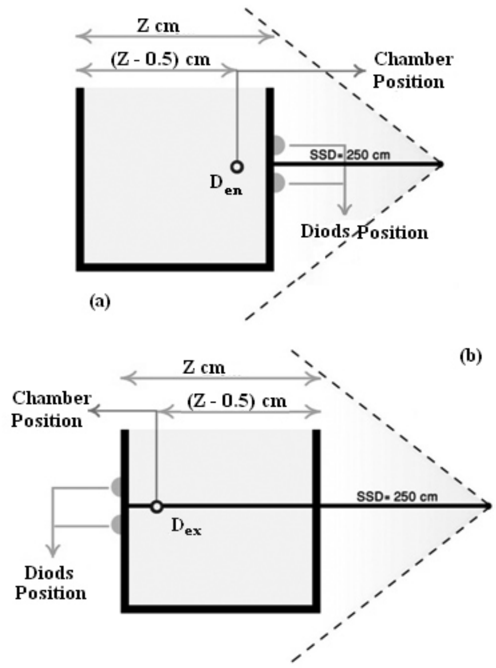

Figure 1. a) Feature of entrance diode calibration, b) feature of exit diode calibration in TBI condition.

Correction factors

Diodes reading are sensitive to many parameters such as SSD, field size, angle of incident and etc; therefore, as stated before, when measurements were performed under various experimental conditions, correction factors were required to account for the calibration of differences [10]. In order to calculate correction factor following equation was implemented:

$$C = \frac{(D/M)_{mea}}{(D/M)_{ref}} \qquad (3)$$

Where $(D/M)_{mea}$ is the ratio of the absorbed dose measured with ionization chamber (D) and the diode reading (M) at experimental condition to that at reference condition.

Field size and SSD correction factors

Due to the similarity of field size and SSD at experimental and calibration situations (SSD= 250cm and field size= 35×35cm^2), no additional correction factors need to be measured.

Directional correction factor

The diodes may show sensitivity variation for angle of incident [3, 10]. In reference condition, diodes were placed at direction of the central axis of beam and the angle of incident was zero, but in clinical condition this angle could be different, so angle correction factor was needed to be measured. For this purpose, similar to that of calibration condition, diodes were taped on the surface of the water phantom and ionization chamber was inserted in the depth of build up (figure 2). Then the ratio of diode and chamber readings was calculated from equation 1.

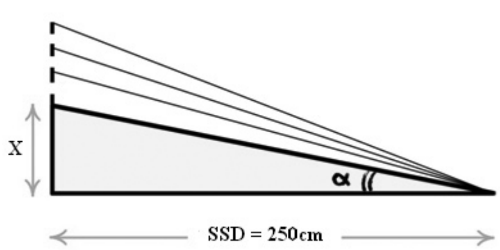

Figure 2. Feature of determination of directional correction factor.

In order to simulate clinical condition, water phantom and diodes were shifted to 30, 45 and 60 cm from central axis of beam respectively. To calculate incident angle at each distance, right-angled triangle equation (4) was used:

$$á = \mathrm{Arctg}(x/y) \qquad (4)$$

Where y=SSD=250 cm and x is the distance of phantom from center axis of beam and α is the angle of incident. Then correction factor at each angle were calculated from equation 3.

Thickness correction factor for exit measurements

Exit diode calibration was measured at 32cm thickness, but the anthromorphic phantom and also patients had different thickness. So, this difference should have been taken in to consideration [10]. For this purpose, slab phantoms with 1cm thickness were used and by putting them next to each other different thicknesses (10, 15, 20, 25 and 32cm) were created (figure 3). Then similar to exit calibration condition, diodes were taped on the exit surface of the phantom and chamber was inserted in the build-up depth. For each thickness, the ratio of the diode and chamber reading was measured and from equations 3 and 4 correction factor was calculated.

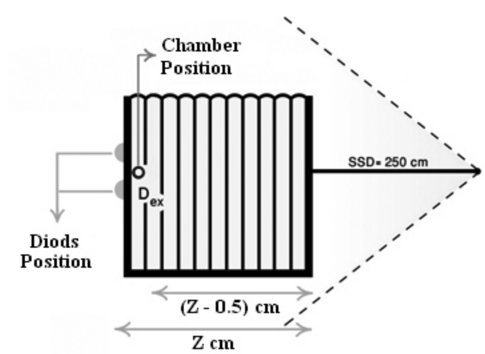

Figure 3. Feature of determination of thickness correction factor.

Complete backscatter

Since the exit dose was not measured in complete backscatter situation, backscatter factor needed to be considered to compensate for the full backscatter loss for exit doses measured with semiconductor diodes [4, 11]. In order to measure this factor, slab phantoms were putted together to create phantom with 32cm thickness. The 0.6cc Farmer chamber was put at depth of 0.5cm from exit surface. To simulate full backscatter condition 7cm Perspex was placed behind the 32 cm slab phantom (figure 4). The ratio of the Farmer chamber at two conditions, full backscatter condition (R_{FB}) and measurement condition (R_{MC}) was calculated from equation bellow:

$$B = R_{FB} / R_{MC} \qquad (5)$$

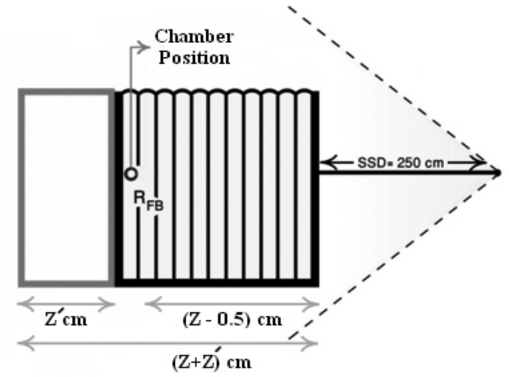

Figure 4. Feature of determination of backscatter correction factor.

Midplane dose determination

In order to calculate midplane dose from surface dose measurements, three algorithms were used. The first algorithm was the arithmetical mean of the entrance and exit doses. The second was the geometric means of the entrance and exit doses and finally the third algorithm proposed as equation (6):

$$D_{mid} = \frac{PDD_{mid} \times D_{en} + \frac{PDD_{mid}}{PDD_{ex}} \times D_{ex}}{2} \qquad (6)$$

Where D_{en} and D_{ex} are entrance and exit dose measured with diodes (with account for correction factors) and PDD_{mid} and PDD_{ex} are percentage depth dose at TBI condition correspond to middle and exit depth of the anthromorphic phantom.

To investigate accuracy in dose delivery 0.3cc ionization chamber was inserted in the middle of the anthromorphic phantom at TBI condition and delivered midplane dose was measured.

RESULTS

The entrance and exit calibration factors for each diode in TBI condition are summarized in table 1. The effect of angle incident on diode response was obtained for each diode and presented in table 2. This table shows the variations of the directional correction factor for T60010L-141 and T60010L-142 are 5.6% and 1.9%, respectively, and, for T60010L-140 and T60010L-143 are below 1%. Figures 5 and 6 show the variation of thickness correction factor for exit diodes, (T60010L-140 and T60010L-142). As it can be seen this correction factor has decreased when increasing the thickness from 10 to 20cm, and it was constant when increasing the thickness from 20 to 25cm, then increased when increasing the thickness from 25 to 32cm. The variation was about 7%.

Table 1. Results of calibration factors of diodes in TBI condition.

Exit calibration factor (mGy/nc)	Entrance calibration factor (mGy/nc)	Diode serial number
4.92	4.07	T60010L-141
4.70	3.78	T60010L-142
4.78	3.86	T60010L-143
4.43	3.71	T60010L-140

A backscatter correction factor B was determined as the ratio of the ionization chamber reading in full backscatter condition (0.543nc) to that of the exit dose measurement condition (0.531nc) for 35×35cm² field size which is used in TBI condition. The correction factor was 1.022.

The ratios of the measured to the calculated midplane doses according to three algorithms are summarized in table 3. It can be seen that the accuracy in the arithmetical, geometric mean and proposed algorithms were about 3.8, 12.5 and 3.3%, respectively.

Table 2. The results of directional correction factor for different incident angle relative to zero incident angles.

Diode serial number T60010L-140	Diode serial number T60010L-143	Diode serial number T60010L-142	Diode serial number T60010L-141	Angle of incident
1.000	1.000	1.003	1.008	6.84
1.003	1.008	1.011	1.020	10.21
1.003	1.008	1.019	1.056	13.49

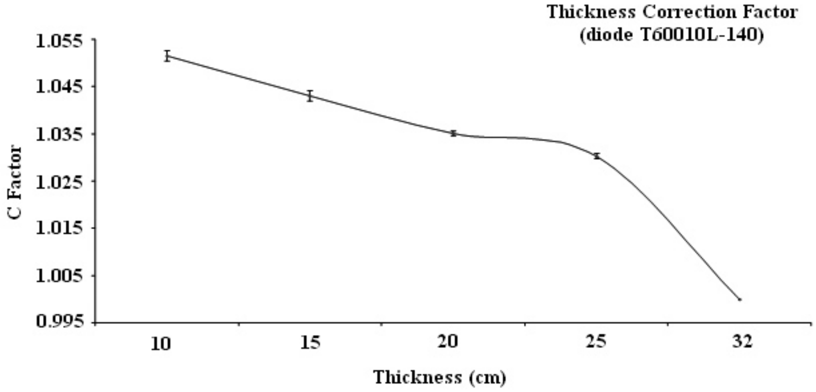

Figure 5. Thickness correction factor as a function of thickness for T60010L-140 diode.

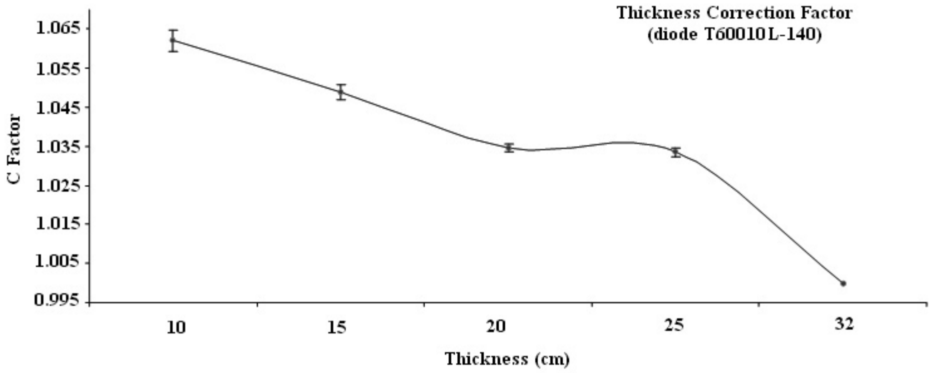

Figure 6. Thickness correction factor as a function of thickness for T60010L-142 diode.

Table 3. Measured midplane doses and calculated midplane doses through three algorithms.

Calculation method	$\frac{D_{mea}}{D_{cal}} \pm SD$
Arithmetical mean algorithm (cGy)	1.038± 0.002
Geometrical mean algorithm (cGy)	1.125 ± 0.003
Proposed algorithm (cGy)	1.033 ± 0.002

The mean difference between the calculated and measured doses in the first algorithm was 0.941 with a standard deviation of 0.608% (p-value=0.054); in the second algorithm, it was 2.817 with a standard deviation of 1.765% (p-value=0.049) and in the proposed algorithm, it was 0.821% with a standard deviation of 0.536% (p-value=0.055).

DISCUSSION

The results in table 1 show that if entrance calibration factors were implied for diodes positioned on the exit surface, dose would be overestimated by about 18%. So, in order to obtain correct doses, entrance and exit calibration of diodes should have been done separately for entrance and exit surface.

These results are compatible with those reported for EDP-30 diodes by Jornet *et al.* [10].

From table 2 it can be seen that the increasing the angle incident of the beam, the increasing of the diode correction factor. The major observed difference resembled those reported by Best *et al.* [12] due to diodes physical structure and was varied from type to type. So, directional dependence was significant and should have been taken into account.

Figures 5 and 6 show the effect of phantom thickness on correction factor, with increasing phantom thickness, phantom scatter increased. Since ion chamber has been more sensitive to scattering than diode, increasing thickness has led to correction factor increase according to equation 3. On the other hand, increasing thickness resulted in hardness of beam and dose rate decrease. Since ion chamber was more sensitive to dose rate than diodes, increasing thickness has led to correction factor decrease. As it can be seen from figures 5 and 6 for thickness up to 20cm, the effect of dose rate was dominant. For thickness of 20 to 25cm, the effect of dose rate was canceled by the effect of phantom scatter. With increase thickness of more than 25cm, the effect of dose rate has been more than that of scatter phantom. It can also be seen variation in thickness correction factor was about 0.7% which was different from the report of Journet [10]. This difference can be signed to rapid decrease of dose in ^{60}Co in comparison with that in 18 MV X-ray generators used by Journet [10].

As mentioned before, the exit dose was measured in lack of backscatter conditions; therefore, for converting the measured exit dose to complete conditions, complete backscatter was used. As it was seen this factor was greater than 1 indicating the increase of absorbed dose due to scattering increase.

It can be seen from table 3 that using the proposed and geometric mean algorithms the calculated dose agreed with the measured dose within 4% which indicated the same order as the experimental error. But, the arithmetical mean algorithm had a larger error and was not acceptable. Among the three algorithms, the proposed algorithm had less error and appeared to be more appropriate for midplane dose determination in TBI condition. The accuracy in proposed algorithm is similar to what obtained by Rizzotti [5]. The results of present study, however showed that the proposed algorithm could be used in TBI treatment being more straight forward than that of Rizzotti method. The proposed algorithm is preferred for its accuracy and simplicity.

CONCLUSION

It is recommended to use diode as a dosimeter for monitoring the delivery of dose to patient receiving TBI. In doing so, calibration and correction factors should be determined for each diode in all relevant clinical conditions. A dose calculation algorithm from exit and entrance dose measurements with diodes has been developed for TBI treatment. The validity of the proposed algorithm has been checked in anthromorphic phantom, with an ion chamber and diodes. The agreement between the measured and calculated midplane dose was excellent. So, the proposed algorithm by this study appears to be useful with accuracy within ±4%.

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