In Vivo Whole Body Dosimetry Measurement Technique of Total Body Irradiation: A 12-Year Retrospective Study Result from One Institute in Thailand

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Objective: *The main problem of total body irradiation (TBI) is how to maintain radiation dose homogeneity throughout the body during a treatment course. The simple set up treatment with non-complicated in vivo dosimetry measurement technique is the ideal method to solve this problem. For this reason, the authors have reported the results of in vivo dosimetry measurement method to prove the reliability of dose distribution from the authors' TBI technique.*
Material and Method: *The authors reviewed the data of dose measurement record from 53 patients' treatment files to report the uniformity of absorbed in vivo dose distribution throughout the whole body from TBI with semiconductor detectors and ionization chamber with the accepted homogeneity within $\pm$ 10% of the prescribed dose. The result was reported in the term of mean and standard deviation of absorbed dose difference from the prescribed dose.*
Results: *The uniformity of radiation dose distribution throughout the whole body of all patients calculated from semiconductors was accepted with mean difference value of -3.2 $\pm$ 2.5% from the prescribed dose and the difference of mean absorbed dose value at midline point between semiconductor and ionization chamber was 4 $\pm$ 3.3%.*
Conclusion: *This TBI dosimetry measurement technique has been proved to exhibit the reliability of dose homogeneity throughout the whole body within the accepted value. This could be applied for use at any institute that has some limitation in resources and small treatment room.*

Keywords: *Total body irradiation, Dsimetry measurement, Bone marrow transplantation*

J Med Assoc Thai 2011; 94 (6): 732-7
Full text. e-Journal: *http://www.mat.or.th/journal*

Total body irradiation (TBI) is a special form of irradiated preparation before bone marrow transplantation for destroying or reducing immune to prevent graft-versus-host reaction and can eliminate some malignant cells that may remain in the body. The challenge problem of TBI is how to maintain the uniformity of scattered radiation in the large irradiated area while minimizing dose to all organs at risk at the same time[1].

TBI has been initiated in the authors' institute since 1989, beginning with *in vitro* radiation dose measurement from cubic water phantom set at determined source-skin-distance (SSD) as a way to adjust the real output dose. A standard dose TBI for myeloablative regimen[2], 200 centrigray (cGy) twice daily (bid) for three consecutive days with a total radiation dose of 1,200 cGy, has been performed since 1997 as an involved part in bone marrow transplantation program.

The objective of the present study was to confirm the reliability of *in vivo* dosimetry measurement of the authors' TBI technique by a retrospective review of the data recorded from patients' treatment files.

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Material and Method

The present study was approved by ethic clearance committee on human rights related to researches involving human subjects, Mahidol

University; protocol number ID 11-52-52. The patients' treatment files were reviewed between 1997 and 2009 for radiation dose measurement data. The TBI technique has been performed by lateral opposed field in supine position (or bended knees if the length of the body extended over the maximum treatment field size) using 6 megavoltage (MV) photon with 350 cm. SSD and collimator head was tilted into 45 degrees to get the maximum coverage diagonal field size from head to feet with gantry angle 90 degree. The treatment regimen was 200 cGy bid in three consecutive days for a total dose 1,200 cGy prescribed at the midline of the body with the dose rate of 0.09 cGy/MU. The total treatment time was about one hour per fraction. The *in vivo* radiation dose measurement throughout the whole body during the treatment was done by pressing 12 semiconductor detectors (Scanditronix Medical DPD-120 pc) throughout the body as shown in Fig. 1. The twelfth semiconductor detector was placed at the gonad position and represented as the midline calculated dose point. To check the accuracy of this dose point, the PTW thimble ionization chamber 0.6 cc was placed nearby the semiconductor detector positioned for recheck the measurable dose and to compare the difference of doses detected by the two methods. The measurable dose from this technique could represent the real *in vivo* dose distribution throughout the whole body and recheck the real midline dose during treatment at the same time. The variation of the patient's shape from head to feet was the main problem of non-uniformity of radiation dose distribution throughout the body. To solve this problem, several small flour or raw rice bags were placed around the patient's body as bolus materials to form the patient's body contour look like a cubic shape for improved uniformity of dose distribution in the target (Fig. 2). The organs at risk (lungs, liver & kidneys and urinary bladder) were shielded by one half-value-layer (HVL) lead blocks, which were placed beside the patient's body. For patients who had previously received cranial irradiation, the five HVL lead block was also placed beside the head to prevent brain injury from radiation. The large Perspex glass plate was placed at 5 cm from body surface to increase scattering electron beam for compensated surface under dosage of photon beam.

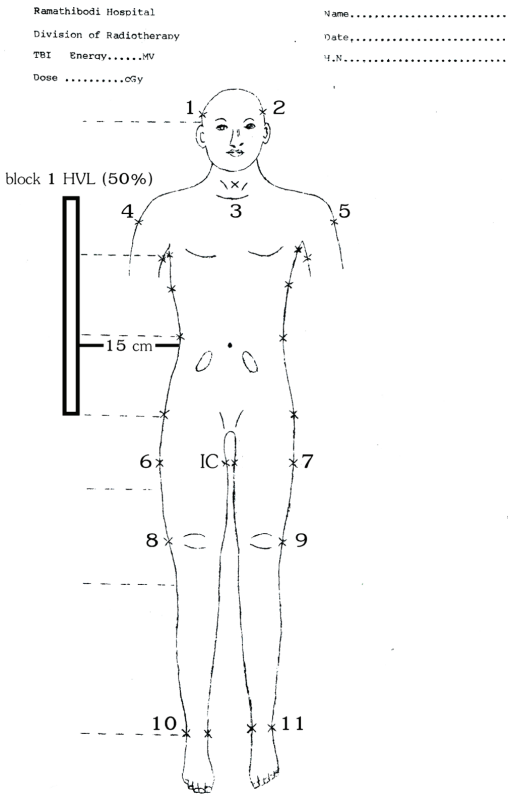

Fig. 1 Twelve semiconductor and ionization chamber positions

Fig. 2 Bolus materials used in TBI

The results were presented in a term of mean and standard deviation of absorbed dose difference from the determined dose measured from every semiconductor's positions and PTW ionization chamber outside the area of lead shields to represent the uniformity of radiation dose distribution and accuracy of radiation dose measurement at midline plane, while dose read inside area of lead shields represented lung dose. The uniformity of absorbed dose distribution and the difference between the two

calculated dose from semiconductor and PTW ionization chamber at midline position were accepted within ± 10% of the prescribed dose.

Results

Fifty-six cases were collected from the record files but excluded three cases due to error of semiconductor measurement during radiation course. Therefore, data analysis was taken from 53 cases. The results are shown in Table 1.

From these findings, it was concluded that:

1) The uniformity of radiation dose distribution throughout the whole body of all patients calculated from semiconductors was accepted with mean difference value of -3.2 ± 2.5% from the prescribed dose.

2) A little difference of mean absorbed dose value at midline point between the semiconductor and PTW ionization chamber was confirmed by mean difference of 4 ± 3.3%.

3) The mean absorbed dose behind one HVL lead shields calculated from semiconductors at shoulder and anterior sternum points was lower than that of the given dose by mean value of -29 ± 17.8%.

Discussion

Non-uniformity of dose distribution in TBI is the main problem caused by very wide treatment field size, variation of patient's body thickness, long SSD, and even scattering radiation from the treatment room's wall[3]. This technique of TBI has been set up to overcome this main problem based on the International Atomic Energy Agency (IAEA) acceptation that the uniformity of dose distribution throughout the body in TBI must be maintained within ± 10% of the prescribed dose[4]. Advantages and disadvantages of this TBI technique can be clarified in the following topics:

1) Patient's supine position during each treatment fraction is the best body position for the comfort of the patient during long time treatment compared with less comfortable in standing, prone, decubitus, or sitting position.

2) Variation of body thickness on the lateral side of the patient can cause less uniformity of dose distribution from opposed lateral field treatment than opposed antero-posterior field. However, the limitation of the treatment room area while concerning comfortability of the patient comfortable is the reason why the authors have decided to use this technique for TBI.

3) The disadvantage in topic 2 can be solved by placing several small flour or raw rice bags around the whole body as bolus materials to make more homogeneity of dose distribution and placed a large Perspect glass beside the bed to compensate surface underdose.

4) Though single wide field irradiation covered from head to feet caused more inhomogeneity of dose distribution than by dividing field into each treatment area (such as each upper and lower half body irradiation), but it can solve the problem of over or underdose at the adjacent treatment fields.

5) To reduce radiation dose to the organs at risk, the supine position with opposed lateral field is easy, to use the patient's arms beside the body as a barrier to block lung and also the square lead blocks placed beside head and along the lateral body from supraclavicular to above lateral iliac crest and pelvic area to shield brain (5 HVL thickness, if indicated) and other critical structures (lungs, liver, kidneys and urinary bladder with 1 HVL thickness). This is very simple to apply without customized block for each patient's need.

6) The measured dose from this technique is relatively reliable by way of *in vivo* dosimetric calculation from semiconductors at the actual treatment time that can be referred to the real whole body's dose. However, the uncertainty of this value may arise from variation of semiconductor's points and position of lead blocks in each treatment fraction.

7) Because the dose prescription point of TBI is usually prescribed at the midpoint of the body,

Table 1. Calculated absorbed dose distribution of the whole body (n = 53)

Calculated absorbed dose point	Mean ± SD (%)*
1. Head (n = 37)	-6.15 ± 10.55
2. Thighs	-3.87 ± 7.58
3. Midline (semiconductor)	-4.70 ± 4.07
4. Knees	0.72 ± 5.26
5. Ankles	-1.94 ± 6.58
Calculation from 1. to 5. (outside lead shields)	-3.20 ± 2.5
6. Anterior sternum	-26.57 ± 19.24
7. Shoulders	-29.29 ± 16.27
Calculation from 6. to 7. (inside lead shields)	-29.00 ± 17.8
8. Midline (PTW)	-6.59 ± 4.89
Difference between 3. and 8.	4.00 ± 3.30

* Percentage of absorbed dose difference from the prescribed dose

proving the reliability of this point dose is very important. This dose measurement method demonstrates no significant difference in comparison dose value between semiconductor and PTW ionization chamber, which can confirm the accuracy.

8) The midline dose value at gonad point does not represent the same midline dose prescribed at an umbilicus as mentioned by IAEA[4]. However, from the fact that umbilical area is shielded by lead blocks and cannot detect the real prescribed dose, the gonad area is the proper point to be chosen for midline dose detected instead.

9) A weak point of this technique is assuming lung dose from semiconductor's value at shoulders and anterior sternum points behind lead shields that can hardly represent the real lung dose.

The results showed that this radiation absorbed dose measurement technique demonstrated the uniformity of absorbed dose distribution throughout the whole body from average semiconductor's dose calculated at head (in cases without lead shield), thigh, knee, ankle and midline positions (outside lead shields) and the reliability of midline dose detected from semiconductor and PTW ionization chamber was varied within $\pm$ 10% of prescribed dose based on the IAEA acceptation. However, when explored into each point dose, the authors found the most variation value (wide SD) from the prescribed dose was detected at the semiconductor's head point (in case that did not apply brain block). The finding can be explained by the irregular shape of the head and neck, which is hard to place the flour or raw rice bags as bolus in the proper place for each treatment session and from fewer patients collected for dose calculation at this point than other locations, which can make more variation than other points. Comparable to the other *in vivo* study with the same treatment technique, the result is still an acceptable result (homogeneity of dose distribution accepted within 5% of prescribed dose)[5-9].

Because radiation pneumonitis is the major dose limiting toxicity for TBI while the real lung dose is hard to identify, finding a way to measure the real lung dose is a challenging problem. By now, relative dose calculation by many experimental ways are used to report lung dose in TBI[6-9]. This TBI technique has assumed the absorbed dose calculated from semiconductors at the midline of anterior sternum and shoulders behind one HVL block to represent lung dose, which is expected to be less than 50% of prescribed dose. However, the result showed average dose decreased only 28% with low reliability of this value (wide SD). This finding may be due to improper methods to detect real lung dose. For example, these semiconductor's points are referred to skin rather than lung dose, and some improper semiconductor's positions that may be placed outside the lead barrier line, which can cause more heterogeneity and higher dose read than expected. However, because of the importance of this issue, it is important to follow-up those patients to see if they develop signs or symptoms of radiation pneumonitis.

In conclusion, this TBI technique was modified in an easiest setup way for patients and workers while accepting the reliability of accuracy in absorbed dose distribution measurement. The advantage of this technique is that it can be applied to any institute that may have some limitation in resources and a small treatment room. However, measurement of lung dose is still a challenging problem.

Appendix (physics calculation method)[10,11]

The Monitor Unit (MU) calculation and diodes for *in vivo* TBI measurement

1. The Monitor Unit (MU) calculation:

1.1 Beam data collection: The percentage depth dose (PDD) normalized at depth 5 cm and measured at 350 cm source skin distance (SSD) and 40 x 40 cm^2 field size were collected. The field size factor was ignored in this calculation.

1.2 In the patient: The maximum thickness at the lateral dimension of a patient was measured for PDD calculation.

1.3 Calculation: MU = Prescribed dose/ (output x PDD x inverse square law), where the prescribed dose point is at the umbilicus of the patient, the output calibrated at 100 cm SSD and normalized at 5 cm depth for 10 x 10 cm^2 field size = 1 cGy/MU and the inverse square law = $(100/350)^2$

2. Diodes for *in vivo* measurement:

2.1 Diode calibration: The DPD-12*pc* diodes (Scanditronix Medical AB) were used for *in vivo* dosimetry in this study.

2.1.1 Sensitivity factor: It is the factor to correct for the response of the detectors themselves. Due to the radiation damage, diodes need to be updated for the correction of decreasing sensitivity.

2.1.2 Correction factor: It is the factor to correct for the response of different reference set-up condition (sensitivity factor) such as energy, field size, SSD etc.

Calibration = Sensitivity x Correction

2.1.3 Set-up methods: The set-up for sensitivity measurement was chosen to be similar to the clinical set-up condition; therefore the correction factor is equal to 1. The water temperature in the phantom was set at 40°C to be analogous to the skin temperature. All 12 front-curved diodes were faced perpendicular to the beam. The gantry was rotated to 90°. The energy, field size and SSD were 6 MV, 40 x 40 cm^2 and 350 cm, respectively. Because diodes were calibrated with the ionization chamber (0.6 cc) as a reference dose, the calibration mode of "calibrate with MU-chamber as reference" was selected. In this set-up condition, the 1,000 MU will obtain 36 cGy at depth 5 cm measured by the ionization chamber (0.6 cc).

2.2 Diode measurement: Twelve diodes were placed at each organ shown in Fig. 1. Right and left lateral fields were used to expose the patient per fraction. Because the average depth is used for MU calculation, dose at the central axis of the head and ankle will represent the absorbed dose more than the prescribed dose. The bolus made of small raw rice or flour bags is used to compensate the result during treatment. Calculated dose at the central axis of each organ = (Diode dose at each organ of right site + diode dose at each organ of the left site)/2 x calibration factor.

Potential conflicts of interest

None.

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เทคนิคการวัดปริมาณรังสีจากร่างกายเมื่อได้รับการฉายรังสีทั้งตัว: การศึกษาย้อนหลัง12ปี ของสถาบันหนึ่งในประเทศไทย

ธิติ สว่างศิลป์, พวงทอง ไกรพิบูลย์, พวงเพ็ญ ตั้งบุญดวงจิตร, จีระภา ตันนานนท์, ทัศนีย์ ลยางกูร, อรวรรณ รัตนสุวรรณ

วัตถุประสงค์*: ปัญหาสำคัญสำหรับ การฉายรังสีทั้งตัวคือจะทำให้ความสม่ำเสมอของรังสีที่กระจายอยู่ในบริเวณฉายรังสีสม่ำเสมอทั้งร่างกายได้อย่างไร การใช้เทคนิคที่ง่ายและไม่ยุ่งยากซับซ้อนที่สามารถวัดปริมาณรังสีจากร่างกายโดยตรงน่าจะแก้ปัญหาได้ดีที่สุด ด้วยเหตุผลนี้ผู้เขียนจึงได้รายงานผลของเทคนิคการวัดปริมาณรังสีจากร่างกาย เพื่อพิสูจน์ความน่าเชื่อถือของวิธีดังกล่าว*

วัสดุและวิธีการ*: ผู้เขียนรวบรวมข้อมูลการวัดปริมาณรังสีในตัวผู้ป่วย 53 ราย ที่ได้มารับการรักษา โดยเทคนิคการฉายรังสีทั้งตัวเพื่อรายงานความสม่ำเสมอของรังสีที่กระจายทั่วทั้งร่างกายโดยใช้ Semiconductor detectors และ Ionization chamber โดยยอมรับความผิดพลาดของปริมาณรังสีที่กระจายทั่วร่างกายผู้ป่วยไม่เกิน 10% ของปริมาณรังสีที่กำหนดในการรักษาจริง โดยรายงานผลค่าเฉลี่ยและค่าเบี่ยงเบนของความแตกต่างจากปริมาณรังสีที่กำหนด*

ผลการศึกษา*: ปริมาณรังสีที่กระจายทั่วร่างกายผู้ป่วยทั้งหมดโดยเฉลี่ยมีความสม่ำเสมอ -3.2% โดยมีค่าเบี่ยงเบน ± 2.5% จากปริมาณรังสีที่กำหนด และความแตกต่างของปริมาณรังสีที่วัดได้ในแนวกลางลำตัวจากปริมาณรังสีจริง เปรียบเทียบระหว่าง semiconductor setector กับ ionization chamber มีค่าเฉลี่ยความแตกต่าง 4% โดยมีค่าความเบี่ยงเบน ± 3.3%*

สรุป*: เทคนิคการวัดปริมาณรังสีวิธีนี้แสดงให้เห็น ถึงความสม่ำเสมอของปริมาณรังสีทั่วร่างกายผู้ป่วยจริง โดยมีค่าความน่าเชื่อถือที่ยอมรับได้ และเป็นเทคนิคที่ง่ายไม่ยุ่งยากซับซ้อน สามารถนำไปใช้ได้ในทุกสถาบันที่มีข้อจำกัดในเรื่องของทรัพยากร และขนาดพื้นที่ห้องฉายรังสี*