THE TECHNIQUE OF TOTAL BODY IRRADIATION APPLIED AT THE LESZCZYŃSKI MEMORIAL HOSPITAL

Aneta Kawa-Iwanicka, Marcin Dybek, Tomasz Iwanicki, Włodzimierz Łobodziec, Andrzej Radkowski

Radiotherapy Department, Leszczyński Memorial Hospital, Katowice, Poland

Received July 2nd, 2001; received in a revised form January 22nd, 2002; accepted February 12nd, 2002

ABSTRACT

Purpose: To improve the reproducibility of patient positioning in fractionated irradiation and to achieve uniform irradiation of the patient, within 12-15Gy, excluding the lungs.

Method: Two special body frames were manufactured, one for treatment planning and the other for the treatment itself. Special tin markers were inserted in the walls to make it possible for a patient to maintain the same position during each fraction of irradiation. Patient treatment was carried out in six fractions (four lateral and two *AP/PA* fields), twice a day, over three consecutive days. The lungs were shielded during *AP/PA* fractions and during one lateral fraction. The shape of the shields for *AP/PA* fields was determined with the use of computer tomography scans, and for lateral fields on the basis of radiographic pictures taken by a simulator. The doses calculated at some selected anatomical points for every patient were checked by *in vivo* measurements which were carried out by means of MOSFET detectors.

Results and conclusions: Reproducibility of patient positioning during consecutive treatments and a uniform total dose distribution over the range of 12 – 15 Gy (except in the lungs) have been achieved. This has been confirmed by *in vivo* measurements.

Key words: TBI, *in vivo* dosimetry, MOSFET detectors.

INTRODUCTION

Total body irradiation (*TBI*) is a method of preparing patients with haematological malignancies for bone marrow transplantation. This technique has been in use since the late 1970s [1]. Originally, *TBI* was applied in the form of a single irradiation. Following reports of late toxicity and late effects of this mode of irradiation, a fractionated *TBI* schedule has been adopted [2,3]. Buchali and co-workers [1] have analysed the immediate toxicity in patients undergoing fractionated *TBI* schedules. A number of irradiation techniques and schedules are now in use [4,5]. The choice of treatment technique varies from centre to centre and depends on the treatment room geometry and the type of treatment unit and dose rate available [6].

At the Leszczyński Memorial Hospital in Katowice, Poland, we have developed a technique of fractionated *TBI.* The main aim of our paper was to assure the same arrangement of every patient during individual fractions of irradiation. Therefore, special body frames were designed for this purpose. These body frames are descrybed below.

MATERIAL AND METHOD

Patient Irradiation

Since August 2000 fifteen patients have been irradiated (their age ranging from 18 to 48 years). All patients were treated in collaboration with the Department of Haematology and Bone Marrow Transplantation of the Silesian Medical Academy in Katowice. Patient data are presented in Table 1.

The procedure for preparing to irradiation is as follows: For every patient,

Proceedings of the Conference “Advances in Radiation Oncology: Diagnosis-Treatment Planning-Clinical Outcome”, Poznań, April 19th – 21st, 2001.

prior to computer tomography, a simulation of patient's arrangement in a special body frame had been carried out. In order to achieve high reproducibility of patient positioning in each fraction of irradiation, two special body frames were made, one for treatment planning (Fig. 1) and the other for the treatment itself (Fig. 2). In the walls of the body frame, made of 1 cm-thick plexiglass plates, special tin markers were inserted. Special marks were drawn on the patient's skin during simulation at places where the laser light went through the selected markers on the body frame walls. These marks helped to arrange a patient in the same position during computer tomography and later during each fraction of irradiation. They also represented points at which *in vivo* measurements were made. Tin markers on body frames walls facilitated reproduction of the patient's position during irradiation, and were also helpful in determining the representative sites on the patient's body for which dose calculations were prepared using the *Helax* treatment planning system. Afterwards points which were drawn on the treatment planning body frame were copied onto the treatment body frame walls. This was possible because the markers were placed identically on the walls of both body frames.

Tab. 1. Data on patients treated by a total body irradiation technique.

Diagnosis	Number of patients
Leucemia lymphoblastica acuta	9
Lymphoma malignum	3
Plasmocytoma	1
Lymphogranulomatosis malignum.	1
Ca embryonale et yolk sac tumor mediastini	1
Total	**15**

The total prescribed dose delivered to the *PC*, a reference point defined at the intersection of the beam axis with the midplane of the patient irradiated laterally, was 12 Gy in 10 cases, and 13,2 Gy in 5 cases, and was delivered in six fractions over three consecutive days. A total body dose should be uniformly distributed in the range of 12 – 15 Gy (total dose to the lungs not exceeding 9 Gy). 15 MV photons from a *Primus* (Siemens) linear accelerator were employed. The patient was treated by a combination of the following fields: lateral fields at a *SSD* of 330 cm, and *AP/PA* fields at 135 cm. The dose-rate measured at a depth of 10 cm in a water phantom for lateral fields was 4,3 cGy/min., and for *AP/PA* fields was 23,6 cGy/min, at the respective *SSD* values.

The lungs during *AP/PA* fractions were protected by shields made of 7 cm Wood alloy, the shape of which was determined from *CT* (computer tomography) scans. For each patient, a set of *CT* scans was taken, with the patient in a supine position placed in the body frame.

For each patient, an irradiation schedule was prepared with an appropriate dose to the *PC*. An example of such a schedule is shown in Tables 2a and 2b. The *AP/PA* fractions, number 4 and number 6 in Table 2a, were split into four (I – IV) individual 54 cm x 54 cm irradiation fields, at *SSD* = 135 cm. The irradiation was carried out twice a day, with an eight-hour break, for three consecutive days. Individual fields I, II, III, and IV covered the head-and-neck, chest-to-pelvis, pelvis-to-knees and the remaining parts of patient's legs, respectively.

Shield positions were determined by the *Helax* planning system and were checked before each *AP/PA* fraction. Shields were then fastened to plexiglass trays inserted in the head of the *Primus* linear accelerator. The lungs were also shielded during one lateral fraction. The shape of this shield was established from radiographic pictures taken by a simulator. During treatment, patients were positioned supine in the treatment body frame, with their arms behind the head (Fig. 2). In order to improve the uniformity of dose distribution, the volume between the patient and the walls of the body frame was filled with bags with rice constituting a bolus (see Fig. 3). The density of rice, 1,37 g/cm^3 was taken

into account in treatment planning. For irradiation with lateral fields, patients had their knees drawn upwards (see Fig. 3). The electron boost to the thorax wall (shielded for 15 MV photons) was delivered with 6 MeV or 9 MeV electron beams.

Fig. 1. Body frame for treatment planning.

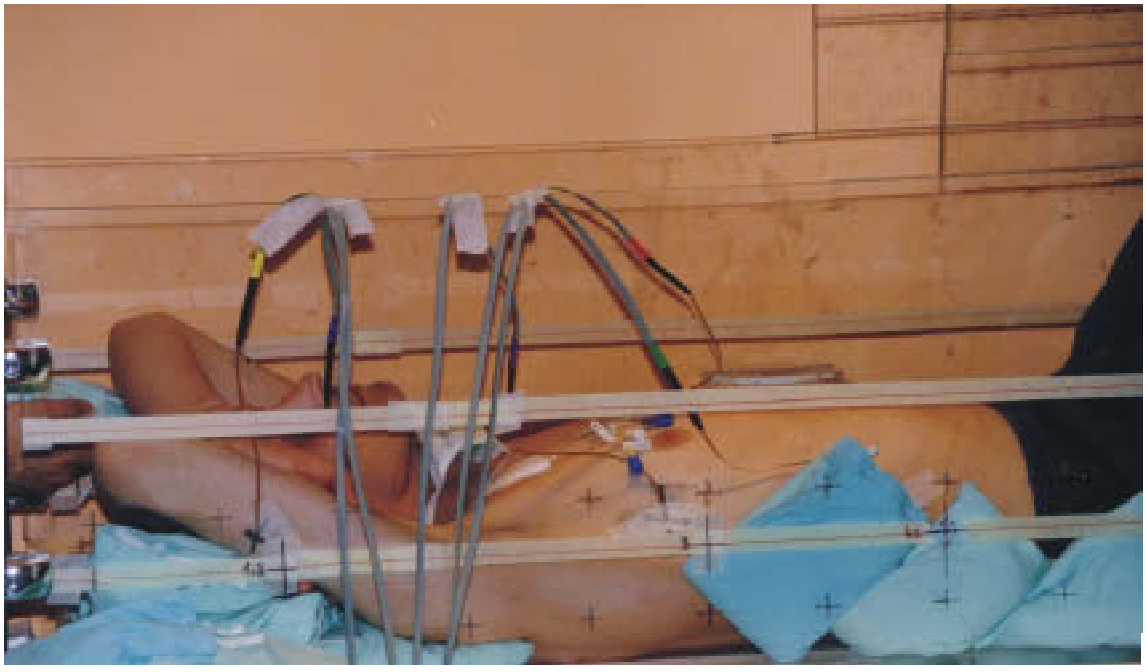

Fig. 2. Patient's arrangement in the therapeutic body frame.

Tab. 2a. Schedule of total body irradiation.

Time of irradiation	Number of fraction	Field's type	*SSD* [cm]	Delivered dose to *PC* [cGy]	Anatomical points for *in vivo* measurements (see table 3)
1st day morning	1	Lateral Left	330	100	1,2,3,4
	1	Lateral Right	330	100	1,2,3,4
1st day afternoon	2	Lateral Left	330	100	6,6a
	2	Lateral Right	330	100	6,6a
2nd day morning	3	Lateral Left shielded for a half of time	330	100	3,4
	3	Lateral Right shielded for a half of time	330	100	3,4
2nd day afternoon	4	*AP* 4 fields See Tab.1b	135	100	2,7,2a,9,5,5a,6,6a
	4	*PA* 4 fields See Tab.1b	135	100	6,6a
3rd day morning	5	Lateral Left	330	100	7,8,10,5,5a
	5	Lateral Right	330	100	
3rd day afternoon	6	*AP* 4 fields See Tab.1b	135	100	7,8,9,10,6
	6	*PA* 4 fields See Tab.1b	135	100	7a,8a,9a,10a, 6a
	7	*AP* electron beam	100	200*	
	7	*PA* electron beam	100	200*	

* Dose delivered to thorax wall.

Abbreviations: *AP* : Anterior – Posterior, *PA* : Posterior – Anterior, *PC* : reference point at the beam axis in the mid - plane from the lateral fields.

Tab. 2b. Schedule of *AP/PA* fractions split into four 54 cm × 54 cm fields at *SSD* 135 cm.

Time of irradiation	Fraction number	Field type	Field number	Anatomical points for *in vivo* measurements (see table 3)
2nd day afternoon	4	*AP* and *PA*	I	2,7,7a (1 or 1a)
			II	8,9,10,3,4
			III	5
			IV	6
3rd day afternoon	6	*AP* and *PA*	I	2,7,7a (1 or 1a)
			II	8a,9a,10a,3a,4a
			III	5
			IV	6

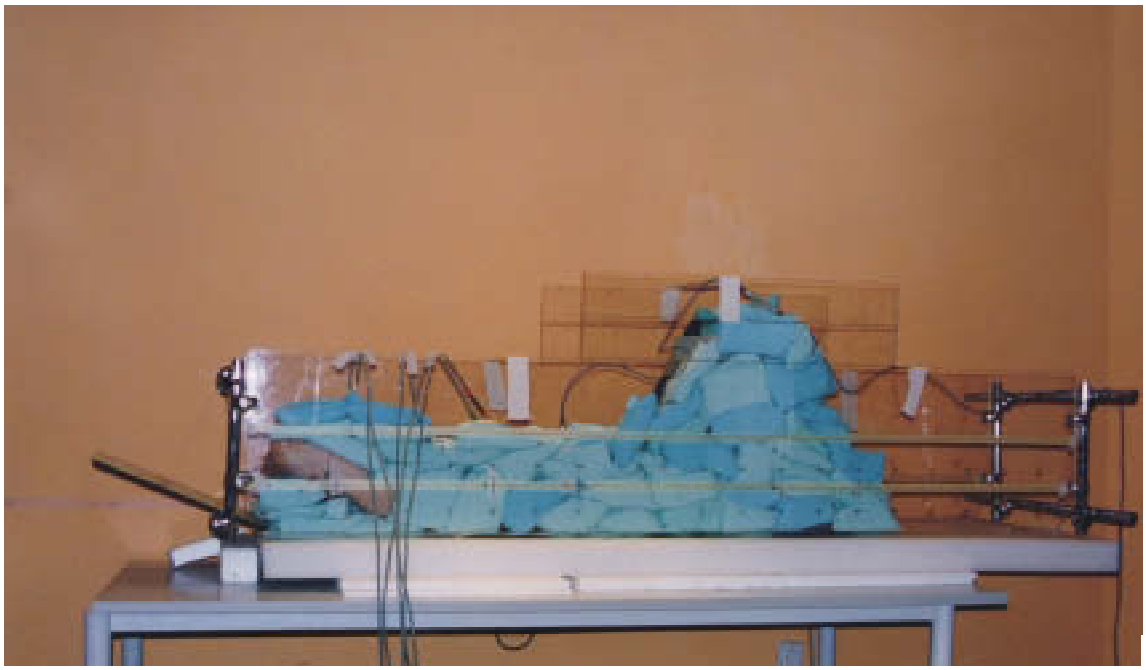

Fig. 3. Patient's arrangement after filling the therapeutic body frame with rice bags.

Dose calculation

For each patient, twenty anatomical points, listed in Table 3, were determined. At these points (on the patient's skin) the doses were calculated and *in vivo* measurements carried out by means of MOSFET (Metal-Oxide Semiconductor Field Effect Transistor) detectors [7,8].

Tab. 3. List of anatomical points for *in vivo* measurements.

Point's number	Place on the patient's body
1	Right side of the arm (1/2 *AP*)
1a	Left side of the arm (1/2 *AP*)
2	Right side of the head (temple 1/2 *AP*)
2a	Left side of the head (temple 1/2 *AP*)
3	Right side of the chest (1/2 *AP*)
3a	Left side of the chest (1/2 *AP*)
4	Patient's right side in the middle of beam (*PC*, 1/2 *AP*)
4a	Patient's left side in the middle of beam (*PC*, 1/2 *AP*)
5	Knee (right side)
5a	Knee (left side)
6	Foot (ankle joint) right side
6a	Foot (ankle joint) left side
7	Forehead
7a	Back of the head
8	Top of the chest
8a	Back of the chest
9	Top of the chest under the lung shield
9a	Back of the chest under the lung shield
10	Point on the abdomen in the middle of patient's length (*PC*)
10a	Point on the back in the middle of patient's length (*PC*)

The MOSFET detectors were connected to a bias supply. After irradiation, the detector was connected to a readout device. The MOSFET detector can accumulate a voltage shift of about 20 V. The sensitive volume of the detectors, of less than 1 mm^3, is encapsulated by approximately 2 mm of epoxy resin, making the detector

flat on one side and hemi-spherical on the epoxy side. The MOSFET detectors were calibrated in a water phantom under conditions of electron equilibrium, using a Farmer 0,6 cm^3 chamber. The calibration coefficient was determined for all five detectors and was equal to 0,906 cGy/mV (standard deviation, SD = 0,0163 cGy/mV). The value of the calibration coefficient did not depend on the side of detector irradiated, within ± 0,1%. The signal of the MOSFET detectors was read out in mV.

As only five MOSFET detectors were available for dose measurements, their locations were changed from one point to another (see Table 2a and Table 2b) in each exposure. Additionally, at some selected anatomical points, ionisation chamber measurements with build-up cup were also performed.

For lateral field irradiation, doses were calculated using percentage depth dose values *PDD* (*SSD* =330 cm, field 40 cm x 40 cm at *SSD* 100 cm) and the radiation beam profile presented in Fig. 4. The *PDD* and the profile were experimentally determined in a water phantom. The profile was measured using a 0.6 cm^3 ionization chamber placed in a water phantom at a depth of 6 cm. The 40 cm x 40 cm x 40 cm phantom was located at *SSD* = 330 cm and was moved across the radiation beam.

To calculate doses for the *AP/PA* fields, the algorithm of the *Helax* treatment planning system was used. The correction for lung density was taken into account for the lateral and *AP/PA* fields.

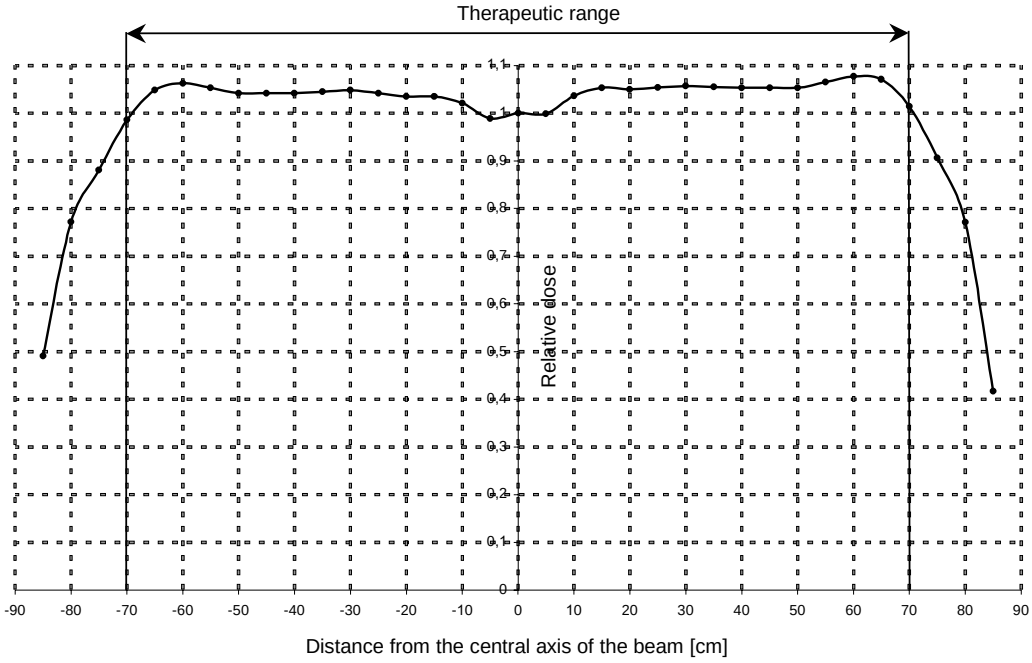

Fig. 4. Beam profile for 15 MV photons (*Primus* accelerator), measured in water at a depht of 6 cm at *SSD* = 330 cm.

RESULTS AND DISCUSSION

Fig. 5 shows the largest discrepancy between the calculated and measured values of the total dose, against the dose prescribed to the *PC*, for all 15 patients. The data indicate that for all patients the values of the calculated total dose at all the twenty points listed in Table 3, apart from those prescribed to the *PC*, ranged between 12 Gy and 14,7 Gy (excluding the lungs). The values of the calculated dose higher than those to the *PC* resulted from the shape of the radiation beam profile (Fig. 4).

For no patient did the maximum value of the measured total dose exceed the value of 15 Gy. In seven patients, the minimum value of the measured total doses was found to be smaller than 12 Gy. For these patients the prescribed total dose to the PC was 12 Gy, and the minimum measured total dose was obtained from detectors placed on the skin surface on the top of their chest (point number 8, Table 3). In this case, the conditions of electron equilibrium around the detector were not fulfilled, for lateral field irradiation, leading to underestimation of the measured dose value. To confirm this finding, during irradiation of patients 14 and 15 the detector was covered by a rice bag, leading to a reduction in the discrepancy between the calculated and measured value of the dose on the skin of the top of the chest. It seems that for *in vivo* dosimetry in the *TBI* technique MOSFET detectors offer an advantage against semiconductor diodes. MOSFET detectors, being calibrated in water under electron equilibrium conditions, are able to evaluate the dose on the skin, whereas a diode, covered by build-up material, provides the value of dose at a maximum dose depth.

Our treatment body frame enabled the patient's position to be stable during irradiation, making the lung shields in *AP/PA* and lateral fields reliable.

CONCLUSION

The results presented in Fig. 5 show that the dose distribution in the patient's body was consistent within the required limits of 12 Gy – 15 Gy. In conclusion, we can state that the required uniformity of dose distribution has been achieved.

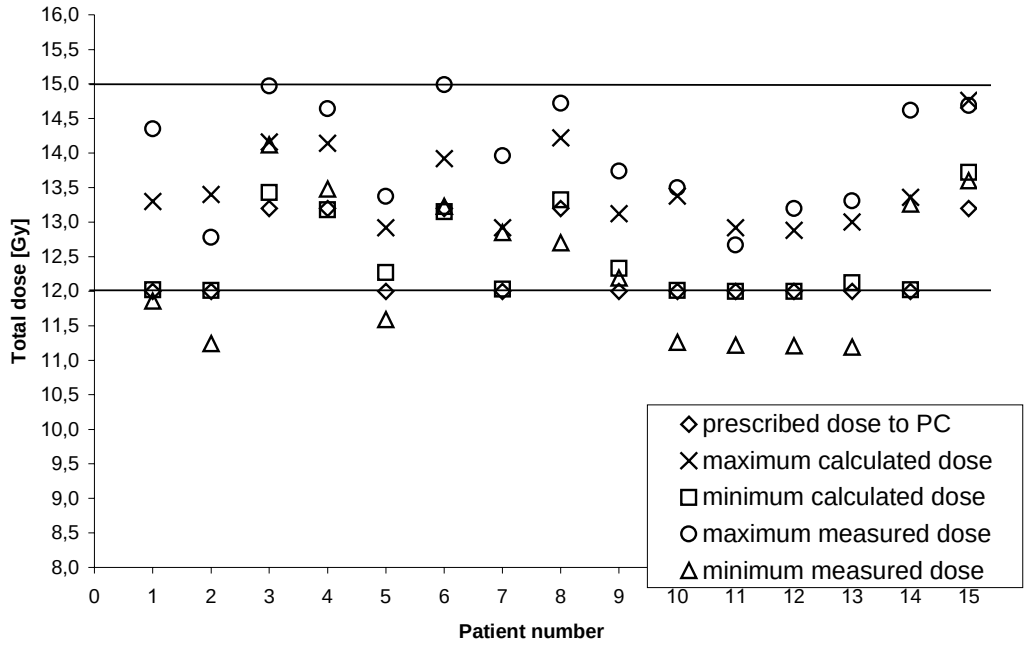

Fig. 5. Values of the total dose prescribed to the *PC* reference point, and of maximum and minimum values calculated and measured for individual patients. Horizontal lines represent the required range of uniformity of total dose values.

REFERENCES

1. Buchali A, Feyer P, Groll J, Massenkeil G, Arnold R, Budach V: „Immediate toxicity during fractionated total body irradiation as conditioning for bone marrow transplantation." Radiother Oncol 2000,54;157-62.

2. Barrett A: „Total Body Irradiation" Rep Pract Oncol Radiother 1999;3:47-64.

3. Akmal Safwart: „The role of low-dose total body irradiation in treatment of non-Hodgkin's lymphoma: a new look at an old method." Radiother Oncol 2000;56:1-8.

4. Quast U „Total body irradiation-review of treatment techniques in Europe." Radiother Oncol 1987;9:91-106.

5. Sanchez-Doblado F, Quast U, Arrans R, L. Errazquin, Sanchez-Nieto B, Terron JA: „Total body irradiation prior to bone marrow transplantation." Report of European Group for Blood and Marrow Transplantation, 1995.

6. Sanchez–Nieto B, Sanchez–Doblado F, Terron JA: „A *CT*- aided *PC*- based physical treatment planning of *TBI*: a method for dose calculation", Radiother Oncol 1997;42:77-85.

7. Ramani R, Russell S, O'Brien P: „Clinical dosimetry using MOSFET", Int. J. Radiat Oncol Biol Phys 1997;37:959-64.

8. Scatchi P, Francescon P: „Calibration of MOSFET detection system for 6-MV in vivo dosimetry", Int J Radiat Oncol Biol Phys 1998;40:987-93.