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Comparison of dose distributions for 6 MV and 15 MV energy for Total Body Irradiation (TBI).

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Abstract

- **Introduction**

Contemporary radiotherapy uses a number of highly specialized irradiation techniques dedicated to well-defined clinical diagnoses. Among these methods are techniques to irradiate the skin (TSEI), bone marrow (TMI) or the whole body of the patient (TBI).TBI has over the last century been used in the treatment of a variety of conditions, both benign and malignant. However, its importance has increased with the development of knowledge about the impact of ionizing radiation on the human body and the development of clinical dosimetry techniques.

- **Aim**

The general aim of the study is to compare dose distributions at selected points of the anthropomorphic phantom under full body radiation conditions for X: 6 MV and 15 MV radiation.Specific objectives are defined: comparison of percent depth and function of photon emission profiles: 6 MV and 15 MV measured with radiofrequency hydrophobic films; measurement of doses in selected cross sections of the anthropomorphic phantom.

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- **Material and method**

A number of measuring devices and materials used in daily work by staff of the Medical Physics Department of the Greater Poland Cancer Centre were used to carry out the study part, but Alderson's anthropomorphic phantom and the radiochromic films in the form of point detectors were essential. In addition to each step of the research part, a special measuring system was prepared to reproduce the conditions prevailing during the TBI session as closely as possible. The research was carried out in three stages: Calibration of radiochromic films;PDD and OCR measurement for: 6 MV and 15 MV photon beam under TBI conditions;Measurement of dose distribution in selected anthropomorphic phantom's cross sections using radiochromic films in the form of point detectors.

- **Results**

For the lateral field irradiated with 6MV photon beam, the maximum compliance (less than 2%) was obtained for the elbows at the entrance and in the center of the phantom; abdomen for the detector positioned in the center of the phantom, the lungs at the entrance and the arms in the middle, and the neck at the position of the film at the entrance. In the case of the lateral field X 15MV, the highest correspondence occurred for the points: the head and the PC in the position of the film in the center of the phantom and the entrance neck. In the case of AP/PA fields for 6 MV energy, the highest compatibility was obtained for the mediastinum in all positions of the film. A small difference was also obtained for the points: head in the middle and at the output of the beam; as well as PC on the output. For AP/PA X 15 MV fields, the highest dose compliance not exceeding 1% was obtained for the location of the neck - at the beam entrance, and the lung and mediastinum at the detector position at the center of the phantom.

- **Conclusions**

On the basis of measurements of dose distribution at selected points of the patient's body for radiation X: 6 MV and 15 MV in the TBI procedure, the following conclusions can be made:Gafchromic EBT (radiochromic type film) can be successfully used for dosimetric measurements, among others. Due to their properties, such as the ability to cut from the sheet of film spot detectors of any shape and size, flexibility, low sensitivity to daylight, resistance to humidity, etc.; Their main drawback is the high cost of buying films and the long time required to prepare the detectors and then read the measured doses. Because of the low popularity of point-based EBTs in point dosing, further research is needed to improve their response to ionizing radiation. There is a noticeable increase in the difference between the dose calculated and measured as the distance between the position of individual detectors increases from the center point.The difference between the dose measured and planned in any of the cases examined does not exceed 9%. The measurements show that the method used is fast, accurate, and can be successfully used as a validation tool not only for the TBI procedure but also for other methods of cancer radiotherapy.

Keywords: TBI, bone marrow transplantation, TBI dosimetry, haematopoietic proliferation, EBT radiochromic

Introduction

Contemporary radiotherapy uses a number of highly specialized irradiation techniques dedicated to well-defined clinical diagnoses. Among these methods are those that allow us to accurately irradiate very small lesions located near critical organs with maximum protection such as stereotactic radiotherapy, CyberKnife, tomotherapy; as well as the techniques by which we can irradiate the skin (TSEI), bone marrow (TMI) or the whole body of the patient (TBI).TBI has over the last century been used in the treatment of a variety of conditions; both benign and malignant. However, its importance has increased with the development of knowledge about the impact of ionizing radiation on the human body and the development of clinical dosimetry techniques. At present, however, this method is primarily used in the treatment of hyperplasia as a mechanism to destroy residual tumor cells and to stimulate the immune system in people who are planning to have bone marrow transplant.

The essence of TBI technique

TBI is a radiotherapy technique that enables large areas of radiation, such as irradiation of the entire body, lymph nodes, while protecting certain groups of organs. Right next to chemotherapy, it is one of the two main elements in the treatment of malignant tumors, especially hematologic malignancies. Although we can distinguish many patterns of patient preparation for transplantation, the most common form of pretransplantation is the combination of these two methods. There are many beneficial biological effects that apply to the use of whole body irradiation that justify the use of this method in people with hematologic malignancies. Among these effects, the elimination of tumor cells and modulation of the immune system play a crucial role. The combination of TBI and chemotherapy leads to immunosuppression, which helps to prevent transplant failure as a graft-versus-host phenomenon that can have serious health consequences, including death of the patient. The success of HSCT, therefore, depends to a great extent on the optimal carrying out of the whole body irradiation procedure [1,2].

Aim

The purpose of the study is to compare dose distributions in the anthropomorphic phantom point scans under X-ray irradiation: 6 MV and 15 MV.

As goals:

- Percentage Depth Dose comparison and Photo Options: 6 MV and 15 MV;
- Measured using radiofrequency hydrophobic films;
- Dose measurements in anthropomorphic phantom choices.

Materials

A number of measuring devices and materials used in daily work were utilized by the staff of the Department of Medical Physics of the Greater Poland Cancer Centre. The following equipment was used:

- Clinical Accelerator Clinac 2300 C-D \ S (Varian, Palo Alto CA, USA);
- Alderson Anthropomorphic Phantom (RSD, Long Beach, CA, USA;
- Gafchromic EBT radiochromic films (ISP);
- IBA I›mRT Phantom;
- PTW Water Phantom;
- Water phantom MP1 by PTW;
- Microtek ScanMaker i900 Scanner.

Methods

- **Measurement of depth dose curves and beam profiles for: 6 MV and 15 MV beams under TBI conditions**

EBT films were cut into 34 strips, each measuring 4.5 cm x 25.5 cm. Previously, their orientation and numbering was determined. For each of the fields, a separate measuring system was prepared consisting of a water phantom – in the case of lateral fields it was a phantom of MP3, while MP1 was used for AP/PA fields.

- **PDD measurement for lateral fields**

Percentage Depth Dose (PDD) is a percentage of the dose rate measured at any depth in the beam axis, in regard to the dose rate measured in the beam axis at the depth of maximum dose rate. Its value depends on the size of irradiation field, source to surface distance (SSD) and radiation energy [18].

In order to measure it, the films are placed in an MP3 phantom on the ruler in such a way that they lie along the axis of the radiation beam. The gantry was rotated to 90°, the angle of the collimator was 45°, the SSD was set to 325 cm. A field size of 40 cm x 40 cm (defined in the isocenter) was set up. The Dose Rate of the accelerator was 100 MU/min. The measurements conditions are shown in Fig. 1.

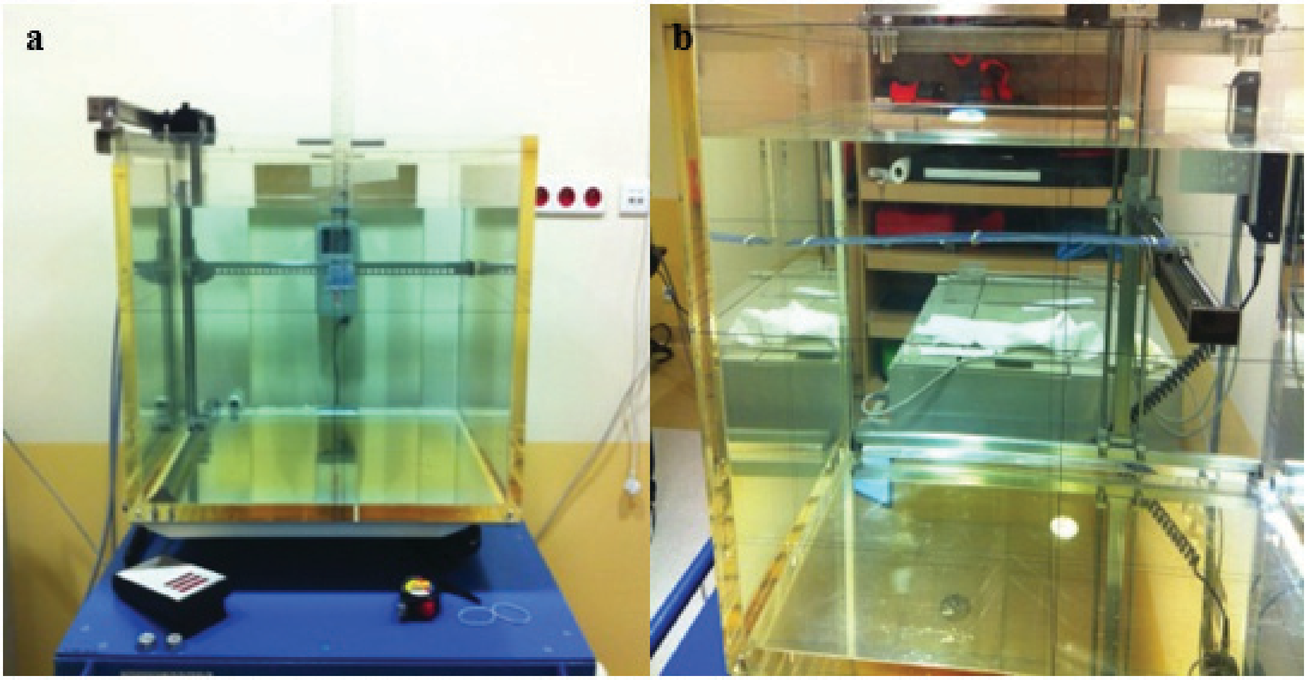


Fig. 1. Measurements conditions of PDD lateral fields a) front view b) side view

Using the treatment planning system (TPS – Eclipse by Varian), the irradiation time was calculated, which was 1900 MU for the photon beam generated by the 6 MV accelerating potential, and 1800 MU for the 15 MV. This was a time equivalent to a dose of 2.2 Gy at the depth of dose maximum. For each of the measured energies the same irradiation field was delivered three times, each time two lines were placed on the ruler, one after the other, so that they take up the entire length of the ruler.

- **Measure PDD for AP/PA fields**

Analogously to the lateral fields measurements for AP/PA fields were performed. To this end, the MP1 phantom was placed under the linac›s head, set to 0°. The angle of the collimator was 90 degrees, the distance of the SSD was 197 cm. A 40 cm x 40 cm box is set. Dose Rate was 100 MU/min. The TPS calculated irradiation time was 650 MU for X6 and 600 MU for X15, respectively. Due to the smaller dimensions of the phantom, a shorter line was used on which one EBT strip was placed. The ruler with the film detector placed on it was placed in the beam axis. In addition, two plates of Plexi were placed over the entire measuring system in order to preserve conditions similar to those prevailing during the TBI screening. As with the lateral fields, the measurements were made three times for each energy.

- **OCR measurement for lateral fields**

The beam profile (OCR – off-center ratio) is a value describing the dose distribution in planes perpendicular to the central axis of the therapeutic beam, i.e. across the axis of the beam [18].

In the MP3 phantom 325 cm away from the camera head set at an angle of 90°, the EBT films are pre-prepared as stripped strips. The films were positioned across the beam axis at a distance of 10 cm from the phantom wall. The treatment scheduling system calculated the irradiation times: 1800 MU for X 6 MV and 1400 for X 15 MV. It was a time equivalent to the 1.5 Gy dose delivered to the film surface. Each time two lines were placed on the ruler one by one. The phantom was set at the beginning of the 56.6 cm field. However, in order to measure the entire beam profile, after the first series of phantom films had been irradiated, the phantom was shifted twice: first about 43 cm, then additionally, by 20 cm. The measurements conditions are shown in Fig. 2.

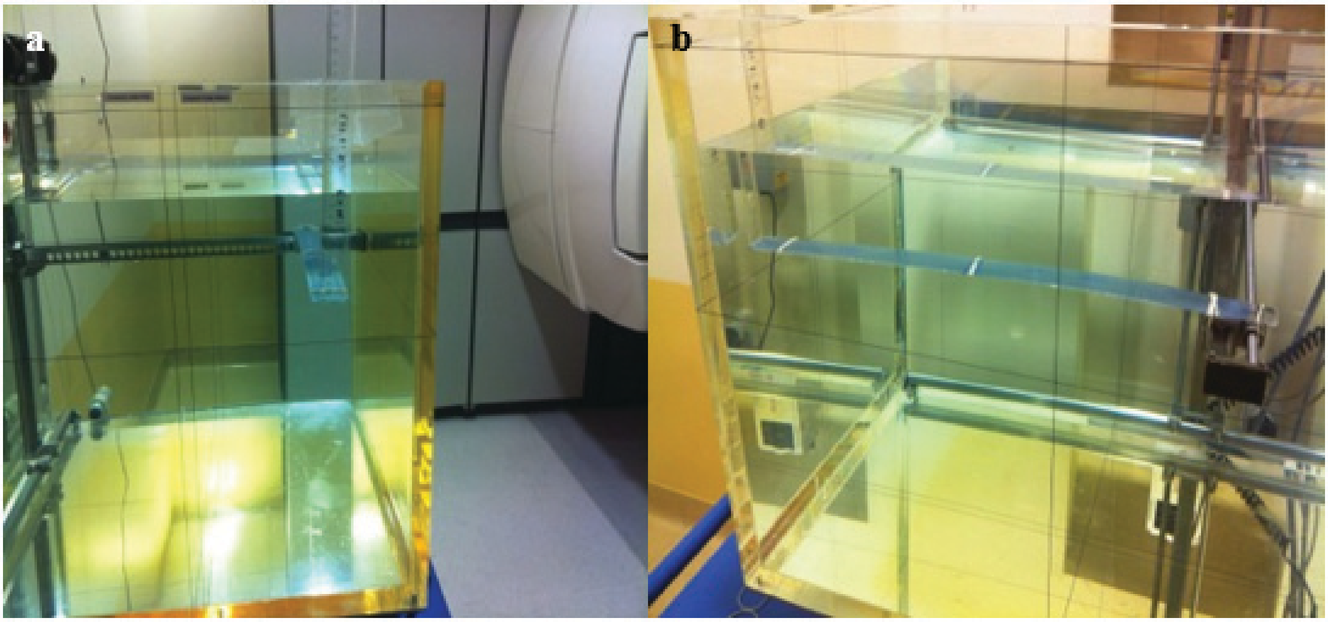


Fig. 2. Measurements conditions of OCR lateral fields a) front view b) side view

- **OCR measurements for AP / PA fields**

At the foot of the profile beam function for AP/PA fields, the phantom MP1 was placed below the accelerator head at 0o. The angle of the collimator was 90°, the dimensions of the field were 40 cm x 40 cm. Dose Rate was the same as measurement for lateral fields. The SSD distance was 197 cm. As with PDG measurements for AP/PA fields due to the smaller phantom dimension, one video is placed on the ruler. This time, however, the films were placed in a phantom at the depth of 5 cm, across the axis of the beam. To measure the entire profile, after the first series had been irradiated, it was necessary to move the phantom twice – first by 20 cm, then by 10 cm. Prior to the TPS measurements, the time of irradiation was 490 MU for X 6 MV and 400 MU for X 15 MV. In order to preserve TBI conditions, two Plexiglas boards were placed above the measuring system.

- **Measurement of dose distributions in selected anthropomorphic phantom cross sections using radiochromic films in the form of point detectors**

The procedure for measuring dose distribution in anthropomorphic phantom cross sections can be divided into several stages:

- Preparation of point detectors from EBT radiochromic films;
- Design of Alderson›s phantom plasters on which the detectors will be placed and placement of the detectors;
- Placing films in the phantom;
- Preparation of measuring system for lateral fields and AP/PA;
- Calculation of irradiation time for individual fields and radiation energy;
- Irradiation of the phantom;
- Dose readings measured with point detectors.

- **Determination of PDG and OCR curves for X 6 MV and X 15 MV**

After performing PDD and OCR measurements in TBI using radiofrequency films, the measured values were scanned using the scanner and the depth-of-field and beam profile was measured. Prior to scanning the film, the manufacturer recommended a six-hour break.At the bottom of the scanner tray the films were sequentially irradiated and then scanned with the calibration curves determined during the calibration measurements of the used EBT radiochromic film batch. The data obtained was read in OmniPro I›mRT (IBA Dosimetry) and then analyzed in Microsoft Excel. Based on the data obtained, PDD and OCR curves were determined for each of the energy and irradiation fields.

From the PDG charts, a percentage of the depth at which the film detectors on the individual slices of the phantom were located was read down. OCR charts, in turn, were used to determine the value of the dose distribution across the beam axis, at the distance at which the individual anatomical points were located from the centering point. The read values were necessary to calculate the dose absorbed by the individual detectors placed on each of the phantom slices. Dependent dose rates and OCR for 6 MV and 15 MV are shown in Tables 1 and 2.

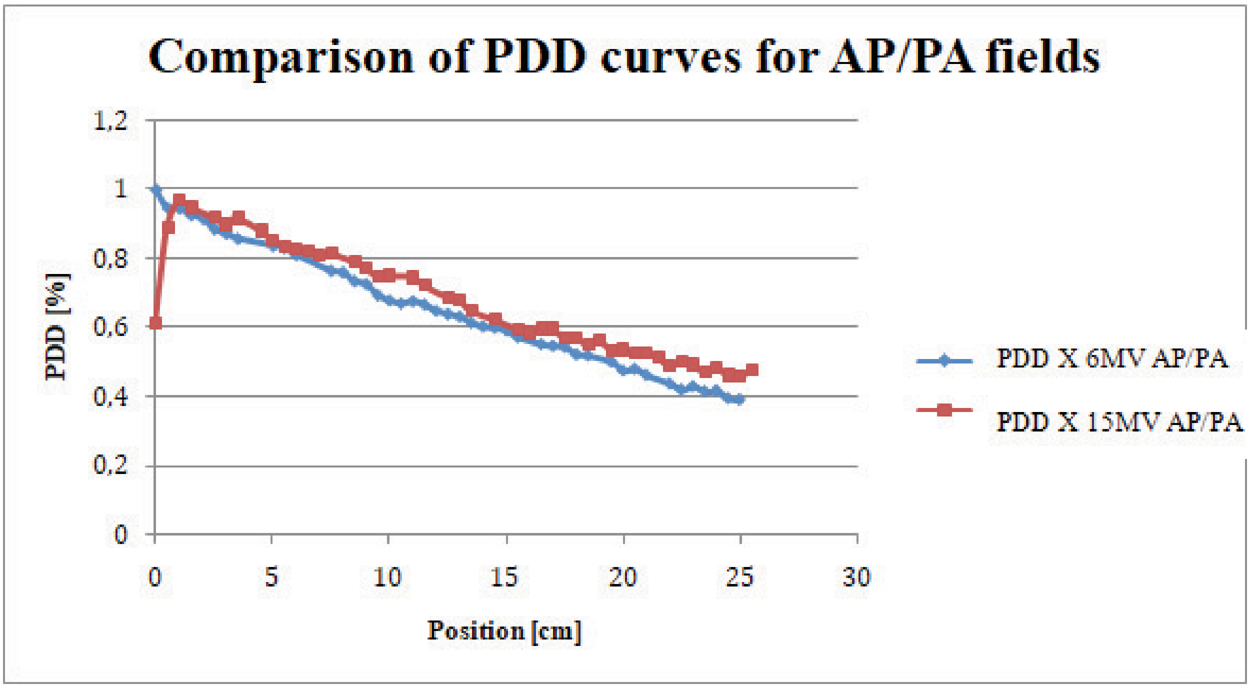
Tab. 1. PDD and OCR for lateral fields, 6MV and 15MV.

		6 MV LAT				15 MV LAT			
Length [cm]	**Anatomical Points**	**PDD in**	**PDD mid**	**PDD out**	**OCR**	**PDD in**	**PDD mid**	**PDD out**	**OCR**
60	HEAD	0.9372	0.8065	0.6520	1.1177	0.9501	0.7936	0.6999	1.0884
45	NECK	0.9372	0.8697	0.7332	1.0751	0.9501	0.8407	0.7528	1.0026
40	ARMS	0.9372	0.5983	0.3425	1.0636	0.9501	0.6075	0.3722	0.9941
35	LUNGS	0.9372	0.5983	0.3425	1.0846	0.9501	0.6075	0.4028	1.0238
30	MEDIASTINUM	0.9372	0.6023	0.3883	1.0907	0.9501	0.6238	0.4193	1.0356
15	ELBOWS	0.9372	0.6982	0.4812	1.0636	0.9501	0.7140	0.4849	1.0086
10	ABDOMEN	0.9372	0.6982	0.4812	1.0907	0.9501	0.7140	0.4849	1.0178
5	WRISTS	0.9372	0.6520	0.4534	1.0602	0.9501	0.6999	0.4633	1.0297
0	PC	0.9372	0.6023	0.3963	1.0000	0.9501	0.6238	0.4313	1.0000

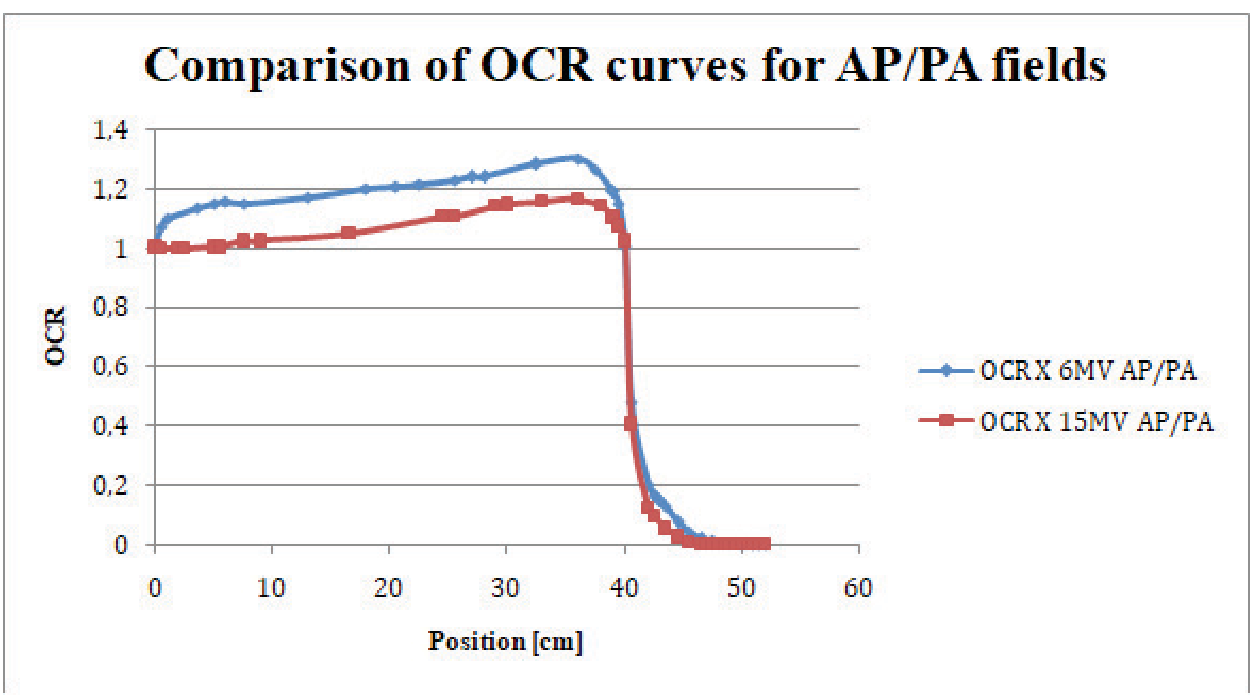
Tab. 2. PDD and OCR for AP/PA fields, 6 MV and 15 MV.

		6 MV AP/PA				15 MV AP/PA			
Length [cm]	**Anatomical Points**	**PDD in**	**PDD mid**	**PDD out**	**OCR**	**PDD in**	**PDD mid**	**PDD out**	**OCR**
30	HEAD	0.9448	0.7247	0.5442	1.0807	0.9644	0.7689	0.5948	1.1454
15	NECK	0.9448	0.8298	0.7247	1.0969	0.9644	0.8327	0.7689	0.9877
10	ARMS	0.9448	0.8099	0.6648	1.0994	0.9644	0.8248	0.7196	1.0114
5	LUNGS	0.9448	0.7588	0.5698	1.1478	0.9644	0.8109	0.5934	1.0000
0	MEDIASTINUM	0.9448	0.7247	0.5442	1.0000	0.9644	0.7689	0.5948	1.0000
15	ELBOWS	0.9448	0.7333	0.5698	1.0969	0.9644	0.7869	0.5840	0.9877
20	ABDOMEN	0.9448	0.7588	0.5897	1.2557	0.9644	0.8109	0.6218	1.2304
25	WRISTS	0.9448	0.7588	0.5698	1.2319	0.9644	0.8109	0.5934	1.1871
30	PC	0.9448	0.7247	0.5410	1.0807	0.9644	0.7689	0.5681	1.1454

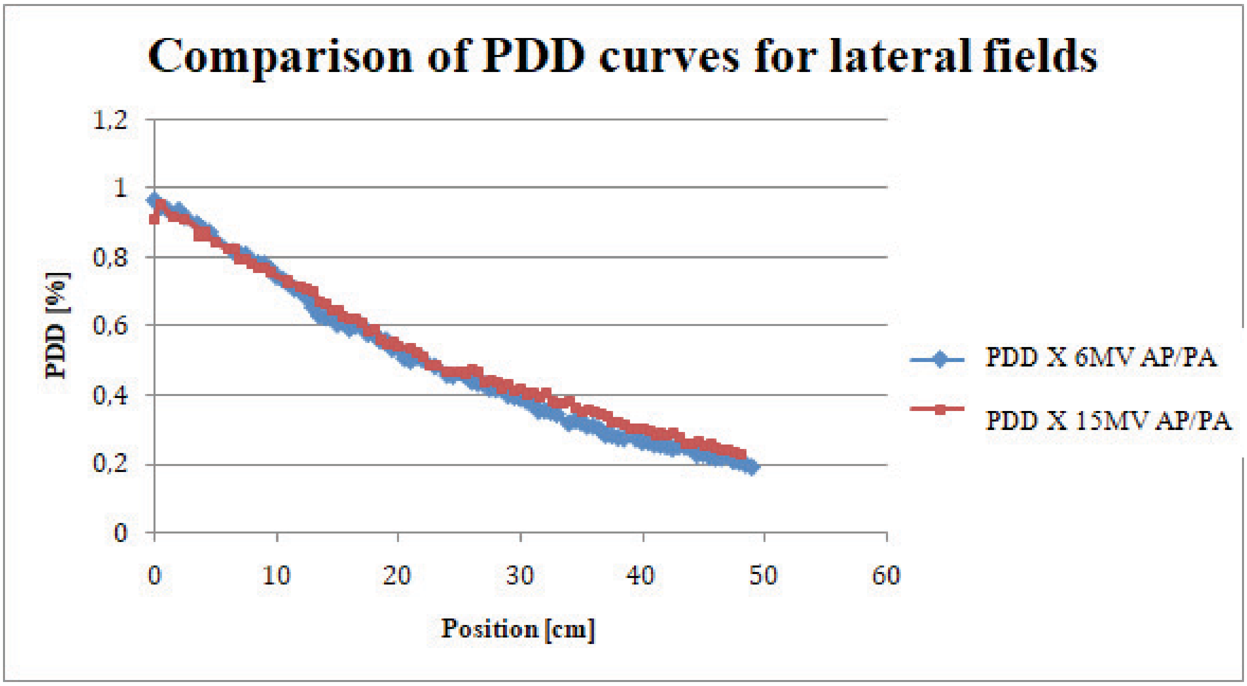
The depth-of-field curves and beam profile functions determined in the course of the measurements do not differ significantly from the shape of the PDD and OCR curves determined in other studies. The deep-root percentage curve consists of three typical areas – build-up, dose point and dose drop. Its shape differs depending on field size and radiation beam energy. Also on the curve of the profile function we can define the areas typical of it: the therapeutic area, the half-shadow area and the shadow area. The following graphs show a comparison of PDD and OCR curves for both energy and irradiation fields.



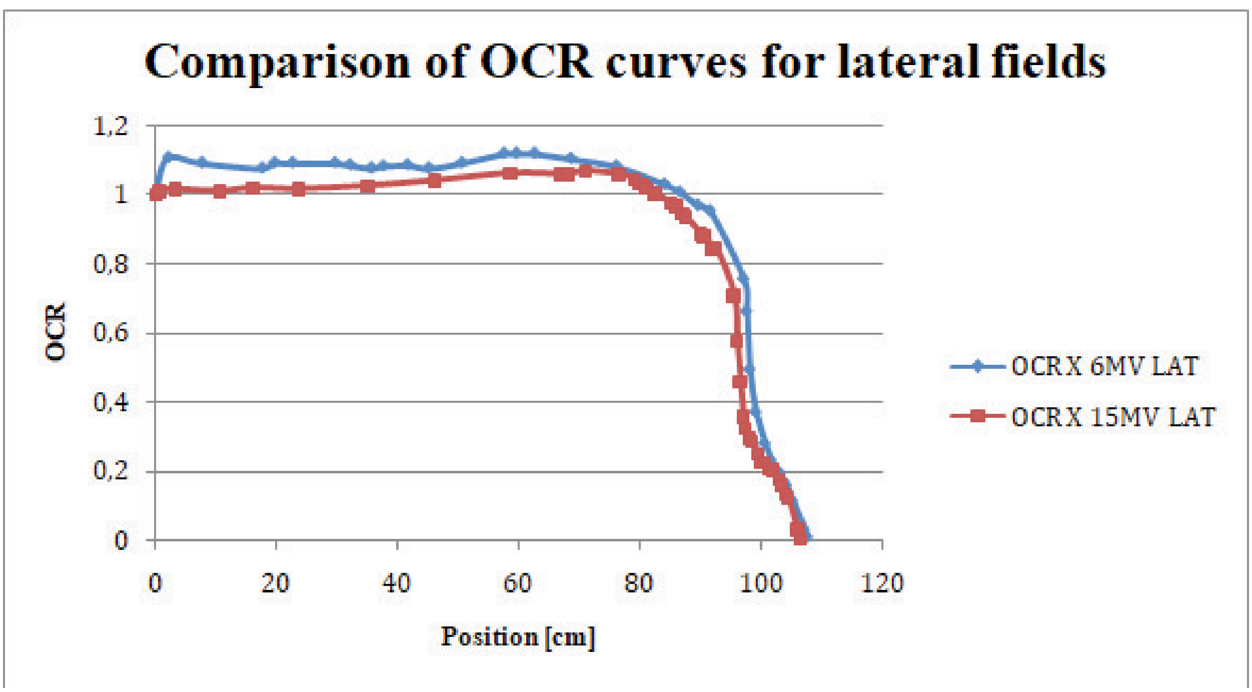
Graph 1. Comparison of PDD curves for AP/PA fields.



Graph 2. Comparison of OCR curves for AP/PA fields.



Graph 3. Comparison of PDD curves for lateral fields.



Graph 4. Comparison of OCR curves for lateral fields.

A significant dose-rise area occurring on the curve, as is the case for the AP/PA deep beam photon beam photon beam with a 15 MV acceleration potential, may indicate that the Plexiglas discs placed over the phantom are too small during the measurement to eliminate the dose escalation effect by generating soft radiation.

- **Comparison of dose distributions at selected Alderson phantom points measured using EBT films in the form of point detectors**

To compare the measured and planned dose distributions, the TBI procedure for Alderson›s anthropomorphic phantom was performed. Spot meters from EBT films were used to measure the dose. Films were appropriately prepared to measure the absorbed dose by calibrating them. The planned dose was determined on the basis of the measured percentage of the deep dose for each energy in the individual phantom measurement points.

Table 3 shows a comparison of dose distribution during TBI in the lateral position of the patient for 6 MV energy. The highest correspondence (less than 2%) was obtained for the following points: the elbows at the entrance of 0.1% and 1.8%; the abdomen at the center of the phantom detector – 0.3%, the lungs at the entrance and the middle arms - – 1.1%, and the neck at the entrance of the film at 1.8%. The highest dose incompatibility (greater than 5%) was obtained at PC: 7.6% at the center of the phantom, the arms at 5.8% at the entrance, the wrists at 5.4% at the center and the mediastinum at 5.5% and lung – 5.3% at the exit. We can also distinguish locations where the measured dose is lower than the planned dose. Too low a dose occurred in all film locations in the head area, in the neck at the entrance and exit of the beam and at the elbows at the beam exit.

Table 4 compares the dose distribution during TBI at the patient›s lateral position for 15 MV energy. In this case, the head and the PC are in the position of the film in the center of the phantom and the entrance of the neck. The difference in these points was less than 2%. The largest discrepancy between measured and planned dose occurred at the mediastinum in the middle position – 8.9%, the lung – 7.8% and the head – 7.2% at the exit, and the arms in the middle position at the center and at the exit of the phantom – 7.1% and 6.2%, respectively. On the other hand, the most under-treated areas (measured dose lower than the planned dose) are the head at the beam input (-7.9%), the elbows (-5.3%) and the neck (-5.2%) at the beam output.

For AP/PA fields for 6 MV energy, the highest correspondence was obtained for the mediastinum in all positions of the film: 0.9% at the entrance, 0.0% at the center of the phantom, and 3.1% at the beam output. Minor differences were also obtained for the following points: the head – 0.4% in the middle and 2.0% at the beam output; and PC at the output – 0.9%. On the other hand, the head, elbows, arms at the beam input and PC at the center showed the largest dose difference ranging between 5% and 9%. The largest irradiation occurred in the area of the abdomen and wrists. The results are summarized in Table 5.

Table 6 shows the results of dose measurement for AP/PA fields with 15 MV energy. The highest compliance rate of no more than 1% was obtained for the neck – at the beam entrance, and the lung and mediastinum – at the detector position at the center of the phantom. Inconsistency of more than 5% occurred for the head points – at the entry, PC – in middle and mediastinum at the exit. The largest inconsistency – between 7% and 9% – occurred for the locations: the neck at the midpoint – 8.9% and the beam output – 7.7%, and the elbows – 7.5% at the midpoint. Within the abdomen, the dose was less than the dose planned for all phantom positions, while in the wrist area it was 4.4% at the beam entrance.

Table 3. Comparison of dose distribution during TBI in the lateral position of the patient for 6 MV energy.

				X 6 MV								
				LAT			LAT			LAT		
Film number	Slice	Length LAT [cm]	Anatomical Points	D planned in [cGy]	D planned mid [cGy]	D planned out [cGy]	D measured in [cGy]	D measured mid [cGy]	D measured out [cGy]	Difference in [%]	Difference mid [%]	Difference out [%]
1	2-3	60	HEAD	342.71	294.92	238.42	328.73	279.01	231.51	-4.1	-5.4	-2.9
2	8-9	45	NECK	329.65	305.91	257.90	335.70	295.85	238.49	1.8	-3.3	-7.5
3	10-11	40	ARMS	326.12	208.19	119.18	344.96	210.53	117.85	5.8	1.1	-1.1
4	12-13	35	LUNGS	332.56	212.31	121.54	336.08	207.80	127.95	1.1	-2.1	5.3
5	14-15	30	MEDIASTI-NUM	334.43	214.93	138.56	325.30	226.04	146.13	-2.7	5.2	5.5
6	20-21	15	ELBOWS	326.12	242.96	167.45	326.32	247.31	158.53	0.1	1.8	-5.3
7	22-23	10	ABDOMEN	334.43	249.15	171.71	333.55	249.84	168.04	-0.3	0.3	-2.1
8	24-25	5	WRISTS	325.08	226.16	157.27	333.55	238.43	155.99	2.6	5.4	-0.8
9	26-27	0	PC	306.62	197.05	129.66	301.35	212.00	134.56	-1.7	7.6	3.8

Table 4. Comparison of dose distribution during TBI in the lateral position of the patient for 15 MV energy.

				X 15 MV								
				LAT			LAT			LAT		
Film number	Slice	Length LAT [cm]	Anatomical Points	D planned in [cGy]	D planned mid [cGy]	D planned out [cGy]	D measured in [cGy]	D measured mid [cGy]	D measured out [cGy]	Difference in [%]	Difference mid [%]	Difference out [%]
1	2-3	60	HEAD	326.43	272.66	240.47	300.70	274.81	257.90	-7.9	0.8	7.2
2	8-9	45	NECK	300.70	266.07	238.25	303.88	276.12	225.98	1.1	3.8	-5.2
3	10-11	40	ARMS	298.15	190.64	116.80	297.09	204.23	124.06	-0.4	7.1	6.2
4	12-13	35	LUNGS	307.05	196.33	130.18	298.26	204.27	140.28	-2.9	4.0	7.8
5	14-15	30	MEDIASTI-NUM	310.59	203.92	137.07	303.24	222.11	143.75	-2.4	8.9	4.9
6	20-21	15	ELBOWS	302.50	227.33	154.38	297.09	216.90	146.20	-1.8	-4.6	-5.3
7	22-23	10	ABDOMEN	305.25	229.40	155.79	295.71	221.60	164.32	-3.1	-3.4	5.5
8	24-25	5	WRISTS	308.82	227.50	150.59	299.95	216.43	146.48	-2.9	-4.9	-2.7
9	26-27	0	PC	299.92	196.91	136.15	292.85	200.00	132.58	-2.4	1.6	-2.6

Table 5. Comparison of dose distribution during TBI at AP/PA patient position for 6 MV energy.

				X 6 MV								
				AP/PA			AP/PA			AP/PA		
Film number	**Slice**	**Length LAT [cm]**	**Anatomical Points**	**D planned in [cGy]**	**D planned mid [cGy]**	**D planned out [cGy]**	**D measured in [cGy]**	**D measured mid [cGy]**	**D measured out [cGy]**	**Difference in [%]**	**Difference mid [%]**	**Difference out [%]**
1	**2-3**	**30**	**HEAD**	281.88	216.22	162.36	306.08	217.18	165.60	8.6	0.4	2.0
2	**8-9**	**15**	**NECK**	286.11	251.28	219.46	285.05	248.65	213.81	-0.4	-1.0	-2.6
3	**10-11**	**10**	**ARMS**	286.76	245.82	201.78	302.69	248.40	208.35	5.6	1.0	3.3
4	**12-13**	**5**	**LUNGS**	299.39	240.45	180.56	304.05	240.25	188.67	1.6	-0.1	4.5
5	**14-15**	**0**	**MEDIASTI-NUM**	260.83	200.07	150.24	263.06	200.00	154.95	0.9	0.0	3.1
6	**20-21**	**15**	**ELBOWS**	286.11	222.06	172.55	307.44	233.47	176.46	7.5	5.1	2.3
7	**22-23**	**20**	**ABDOMEN**	327.53	263.05	204.43	299.98	252.47	198.27	-8.4	-4.0	-3.0
8	**24-25**	**25**	**WRISTS**	321.32	258.06	193.79	314.91	242.97	179.85	-2.0	-5.9	-7.2
9	**26-27**	**30**	**PC**	281.88	216.22	161.41	294.29	234.14	162.88	4.4	8.3	0.9

Table 6. Comparison of dose distribution during TBI at AP / PA patient position for 15 MV energy.

				X 15 MV								
				AP/PA			AP/PA			AP/PA		
Film number	**Slice**	**Length LAT [cm]**	**Anatomical Points**	**D planned in [cGy]**	**D planned mid [cGy]**	**D planned out [cGy]**	**D measured in [cGy]**	**D measured mid [cGy]**	**D measured out [cGy]**	**Difference in [%]**	**Difference mid [%]**	**Difference out [%]**
1	**2-3**	**30**	**HEAD**	287.33	229.08	177.21	301.73	235.70	183.99	5.0	2.9	3.8
2	**8-9**	**15**	**NECK**	247.77	213.93	197.54	247.85	232.98	212.77	0.0	8.9	7.7
3	**10-11**	**10**	**ARMS**	253.71	216.99	189.31	251.31	225.34	197.91	-0.9	3.8	4.5
4	**12-13**	**5**	**LUNGS**	250.85	210.93	154.35	243.46	210.89	161.36	-2.9	0.0	4.5
5	**14-15**	**0**	**MEDIASTI-NUM**	250.85	200.00	154.72	247.33	200.00	163.87	-1.4	0.0	5.9
6	**20-21**	**15**	**ELBOWS**	247.77	202.17	150.04	251.31	217.36	155.68	1.4	7.5	3.8
7	**22-23**	**20**	**ABDOMEN**	308.65	259.52	199.00	294.63	242.57	192.87	-4.5	-6.5	-3.1
8	**24-25**	**25**	**WRISTS**	297.79	250.39	183.23	284.57	253.21	188.48	-4.4	1.1	2.9
9	**26-27**	**30**	**PC**	287.33	229.08	169.26	292.26	240.91	163.35	1.7	5.2	-3.5

Discusion

Dose measurement in vivo during the TBI procedure is a topic of many scientific papers that use different measurement methods. TIR detectors, semiconductor detectors, Mosfet detectors and EBT radio-video are used to measure doses in TBI procedure. In the work to measure the dose used EBT radiochromatic films, which made point detectors, by cutting them. The dose measured by EBT films and TLDs by F. Su, C. Shi, S. Stathakis, and N. Papanikolau [19] was compared to the dose of total body irradiation radiotherapy. Dose measurement was made using the anthropomorphic phantom, with films oriented perpendicular to the axis of the radiation beam.

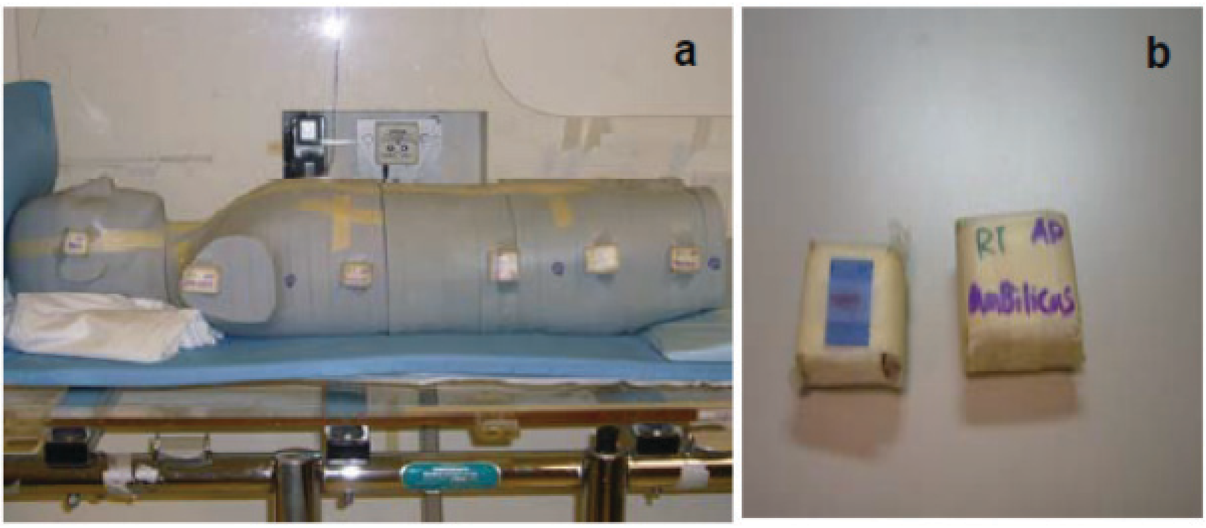


Fig. 3. Anthropomorphic phantoms (a) and bolus detectors (b).Source: Su F., Shi C., Stathakis S., Papanikolaou N., Application of Gafchromic EBT. Phys. 34, 2420 (2007);

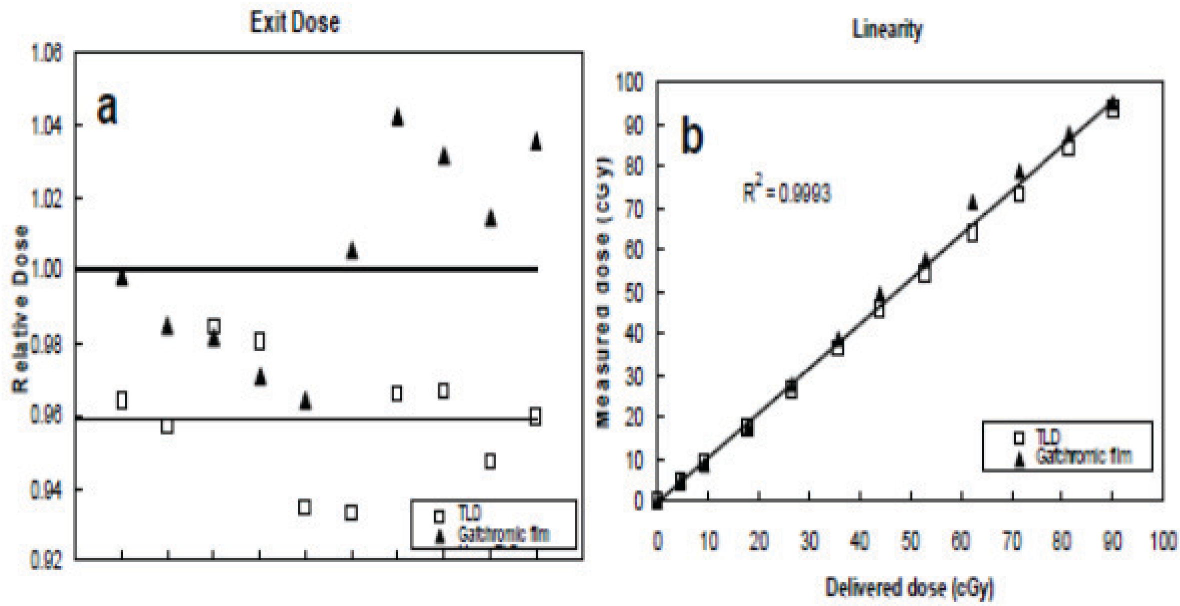
The table below shows the results. The discrepancy between the planned dose and the film measured was not greater than 3.5%, while the difference between the measured film and the TLD ranged from 0.55% to 4.08%.

Table 7. Results obtained by measuring films and TLD detectors for six anatomical points.

Anatomical regions	Separation (cm)	D(CAX, cGy)	Difference % (Film vs. prescription dose)	D(TLD, cGy)	Difference % (TLD vs film)
Head	7.9	101.5	1.46	103.6	-2.02
Shoulder	38.1	100.9	0.93	105.0	-3.83
Chest	30.8	97.8	-2.21	97.3	0.55
Umbilicus	28.4	100.0	0.04	103.3	-3.18
Hip	30.8	97.4	-2.58	101.6	-4.08
Thigh	31.0	96.9	-3.15	99.2	-2.33

Source: Su F., Shi C., Stathakis S., Papanikolaou N., Application of Gafchromic EBT. Phys. 34, 2420 (2007);

The graphs below show the comparison of the starting dose obtained during EBT film measurement, TLD detectors and TBI ionization chamber. It follows that both TLDs and EBT radios can serve as a measurement method for TBI.



Graph 5. Comparison of the output dose variability between EBT, TLD and ionizing atmosphere under TBI (a) and doses measured by films and TLDs as delivered by the ionizing chambers.
Source: Su F., Shi C., Stathakis S., Papanikolaou N., Application of Gafchromic EBT. Phys. 34, 2420 (2007);

Authors C. Esquivel, M.S. Smith, S. Stathakis, A. Gutierrez, C. Shi, N. Papanikolau in In Vivo Dose Measurements for Total Body Irradiation [20] describe the results of dose measurement during the TBI procedure using three measurement methods: ROSS ionization chamber, TLD and optical detectors OSLD. The TBI procedure was performed using 6 MV photon energy on the Varian 600C linear accelerator. In order to achieve maximum field size, the accelerator head was twisted by an angle of 90⁰, the distance from the radiation source to the patient›s body was 350 cm. The set dose was 100 cGy at the depth of 10.5 cm.

The results of the dose measured with two types of measuring detectors are shown in the table below. The difference between the dose measured by TLD and OSLD detectors ranged from - 7.6% to 0.2%.

Table 8. Comparison of results obtained with TLD and OSLD detectors.

Site	Average TLD Midplane Dose	Average OSLD Midplane Dose	Percent Difference
Head	107.9	101.60	-6.2%
Neck	106.6	105.17	-1.4%
Shoulder	99.9	98.55	-1.3%
Mediastinum	102.3	97.67	-4.7%
Umbilicus	93.2	91.22	-2.2%
Hip	95.8	91.17	-5.1%
Thigh	101.9	94.70	-7.6%
Knee	101.3	101.50	0.2%
Ankle	101.8	100.55	-1.3%

Source: Esquivel C., Smith M.S., Stathakis S., Gutierrez A., Shi C., Papanikolau N., In Vivo Dose Measurements for Total Body Irradiation, AAPM Annual Meeting, July 2009 Anaheim, California

The study also compared the dose difference measured between the three skin surface measurement methods with respect to the ROSS ionization chamber. This difference was not greater than ± 3%.

Table 9. Comparison of dose differences measured using three measurement methods with respect to the ROOS ionization chamber.

Dosimeter	Surface dose measurement	% difference from ROOS
ROOS	135.5	-
OSLD	138.9	2.4%
TLD	132.6	-2.2%

Source: Esquivel C., Smith M.S., Stathakis S., Gutierrez A., Shi C., Papanikolau N., In Vivo Dose Measurements for Total Body Irradiation, AAPM Annual Meeting, July 2009 Anaheim, California.

Despite numerous scientific papers showing dosimetric measurements under full-body irradiation, little is known about the use of radiofrequency spot-spot radiographs for this purpose. The results of the research show that this method can be successfully used in the day-to-day operations of dosimetric facilities. EBT radiochromic films have a number of advantages, such as high spatial resolution, low daylight sensitivity, ability to trim a sheet of film to the desired size and shape, possibility to immerse the film in water without risk of damage and also the fact that these films are self-developing.The presented dosimetric procedure using EBT detectors is a quick and convenient method for measuring the deep dose and the beam profile function, where instead of scanning individual points using the ionization chamber, the entire measurement can be collected using one long piece of a film. As demonstrated, the PDD and OCR curves determined by the films show the shape and pattern typical of this type of curve defined in other studies; keeping all the characteristic points. It should be emphasized that the TBI dose verification method using radiochromic films in the form of point detectors is not suitable for use in patient measurements due to the fact that the detectors would have to be placed on the patient›s body perpendicular to the radiation beam axis, Covered with boluses to provide the right build-up. EBT films, however, are an excellent phantom validation tool for verifying a new treatment regimen (e.g. fractionation, patient positioning, etc.) so that they can be used not only for TBI measurements but also for other methods of cancer therapy.

Conclusions

Based on measurements of dose distribution at selected points of the patient›s body for radiation X: 6MV and 15MV in the whole body radiation procedure, the following conclusions can be made:

- EBT radiochromic films can be successfully used for dosimetric measurements, inter alia, due to their properties such as: the ability to cut from a sheet of film any point detector of any shape and size, low daylight sensitivity, dampness resistance to humidity, etc.;
- The major disadvantage of the chosen measurement method is the high cost of buying the films and the long time required to prepare the appropriate detectors and then read the measured dose values;
- Due to the low popularity of dosimetric measurements with radiofrequency films in the form of point detectors, further research is needed to improve their readings on ionizing radiation;
- There is a noticeable increase in the difference between the dose calculated and measured as the distance between the position of individual detectors increases from the center point;
- The difference between the dose measured and planned in any of the cases examined does not exceed 9%;
- Conducted measurements using EBT motion detectors show that this method is fast, accurate, and can be successfully used as a validation tool not only for full body radiation but also other methods of cancer radiotherapy.

Literature

[1] Joint publication, Whole Body Radiotherapy, Guidelines in Radio – Oncology, June 2003;
[2] Podgorsak E. B., Radiation Oncology Phisics: A Handbook for Teachers and Students, IAEA, Vienna 2005, s. 516 - 521;
[3] www.szpik.info, entrance: 22.06.2013r.;
[4] Joint publication, Białaczka i inne choroby nowotworowe krwi. Mały poradnik pacjenta, Klinika Hematologii Collegium Medicum Uniwersytetu Jagiellońskiego, Kraków;
[5] Konopka L. (red.), Choroby rozrostowe układu krwiotwórczego;
[6] Krajowa Baza Danych Nowotworowych, http://epid.coi.waw.pl/krn/, entrance: 25.06.2013r.;
[7] www.leukemia.pl/rodzaje-transplantacji.html, entrance: 02.07.2013r.;
[8] Barker Ch. A., Yahalom J., Total Body Irradiation, [w:] Gunderson L.L, Tepper J.E., Clinical Radiation Oncology, Elsevier 2011, s. 345 – 359;
[9] Malicki J., Zwierzchowski G., Piotrowski T., Kosicka G., Rozkłady dawek podczas napromieniania całego ciała, Zeszyty Naukowe Wielkopolskiego Centrum Onkologii, Poznań 2006, 3(2) 47 – 63;
[10] Quast U., Whole body radiotherapy: A TBI-guideline, Jourlal of Medical Physics 2006, (31): 5 – 12;
[11] Galvin J. M., Total Body Irradiation. Dosimetry and Practical Considerations, Thomas Jefferson University Hospital, Kimmel Cancer Center, Philadelphia;
[12] Joint publication, The physical aspects of Total and half body photon irradiation, AAPM Repport No. 17, 1986;
[13] The Alderson radiation therapy phantom. The worldwide standard for quality assurance for radiation therapy, www.rsdphantoms.com/rt_art.htm, entrance: 04.04.2013r.;
[14] User Guide: Gafchromic EBT Self – Developing Film For Radiotherapy Dosimetry, 2006;
[15] User Giude: I'mRT Phantom, A smart modular phantom, IBA 2009;
[16] www.ptw.de, entrance: 17.06.2013r.;
[17] www.microtek.com, entrance: 18.06.2013r.;
[18] Piotrowski T., Wybrane zagadnienia dotyczące planowania leczenia w radioterapii. Poznań, Wielkopolskie Centrum Onkologii;
[19] Su F., Shi C., Stathakis S., Papanikolaou N., Application of Gafchromic EBT Film for in Vivo Dosimetry with Total Body Irradiation (TBI) Radiotherapy. Med. Phys. 34, 2420 (2007);
[20] Esquivel C., Smith M.S., Stathakis S., Gutierrez A., Shi C., Papanikolau N., In Vivo Dose Measurements for Total Body Irradiation, AAPM Annual Meeting, July 2009 Anaheim, California;
[21] Malicki J., Kosicka G., Stryczyńska G., Wachowiak J., Porównanie rozkładu dawek w ciele chorego podczas napromieniania całego ciała w technice radioterapii Co-60 i akceleratorem X 15MeV. Reports of Practical Oncology and Radiotherapy, 1999, 4(4): 116;
[22] Malicki J., Kosicka G. Napromienianie całego ciała dawką 5 Gy w chorobach rozrostowych układu krwionośnego. Report of Practical Oncology and Radiotherapy, 2004, 9 (S2): 264;