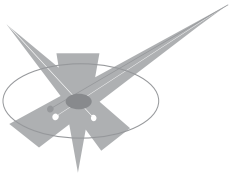
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The rotary dual technique for total skin irradiation in the treatment of mycosis fungoides – a description of the applied method

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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Summary

Background The aim of total skin electron irradiation in the therapy of mycosis fungoides is to obtain total or partial remission of the disease while concurrently lowering the toxicity level. Total skin electron radiotherapy should fulfill the EORTC requirements from the year 2002.

Aim The aim of this work is to present the rotary dual method for total skin electron irradiation used in the Great Poland Cancer Centre including its specific technical and physical aspects. These aspects include the parameters and conditions for the treatment (geometrical conditions of the technique, homogeneity of the dose, patient's positioning, additional fields and the method of dose fractionation), the absolute dosimetry (parameters and functions characterizing the electron irradiation beam used in the rotary dual method of the rotary dual method of the total skin electron irradiation) and *in-vivo* dosimetry conducted during the therapy with rotary dual fields, which allowed to control the dose distribution and to indicate additional skin areas, which should be irradiated with local fields.

Materials/Methods The rotary dual method of the Total Skin Electron Irradiation proposed by the author, is based on the combination of the two most frequently used methods: 1) six dual fields' method and 2) rotary method. The original, calculation algorithm elaborated by the author was based on the two dimensional algorithm proposed by Podgorsak et al.

Results The new algorithm, proposed by the author takes into the changes in doses along the vertical and horizontal axis of the object. Moreover the elliptical; shape of the object proposed by the author, is more approximated to the shape of the patient than the cylindrical object proposed by Podgorsak et al.

Discussion Parameters used by authors: nominal energy – 6MeV, mean energy at the skin surface – 2.8MeV, values of the PDD (at the skin surface – 100%, at the 4mm – 83.6% and at the 20mm – 1.8%), SSD – 300cm, field size equal to 230cm by 115cm, fraction dose – 1.5Gy, total time of treatment from 6 to 7 weeks were compatibility with EORTC recommendations.

The elaboration of the rotary – dual method of total skin electron irradiation allowed to reduce SSD distance compared to irradiation with the rotary method. Moreover the dimension of most therapeutic rooms is usually too small to realize

the total skin electron irradiation methods with SSD distance higher than 350cm. Patient set-up and rotation during irradiation (based on rotary method) allow to reduce the number of dual fields used in Stanford method from six fields to one dual field (rotary-dual method). This modification leads to reduction of time assigned for set-up verification). Presented results of *in-vivo* dosimetry for selected patients treated in Great Poland Cancer Centre confirm the needfulness for using additional local for areas of perineum, scalp vertex, hands, neck-shoulders, plants.

Moreover, obtained results indicate that total dose prescribed for additional fields depends on height and obesity and should be prescribed individually for each patient.

Key words **total skin electron irradiation • mycosis fungoides**

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Background

The aim of total skin electron radiotherapy (TSEI), used in the treatment of mycosis fungoides, is to obtain total or partial remission of the disease while maintaining low treatment associated toxicity. The main aim is to obtain a homogeneous dose in the whole irradiated area (target volume – epidermis, adnexal structures, dermis) [1,2]. It is also required to assure the greatest comfort for the patient during the procedure. Total skin electron radiotherapy should fulfill the requirements of EORTC from the year 2002 [3]. Those requirements refer to methods of qualifying patients, methods of performing the treatment (geometrical conditions of the technique, homogeneity of the dose, patient positioning, additional fields and the methods of dose fractionation) and methods for minimizing toxicity levels and discomfort arising from the treatment.

The most frequently used methods for total skin electron irradiation are: a/ the method of six dual fields and b/ the rotary method [1,4–8]. In the first case the patient is irradiated with six dual fields (six different setups) [1]. The size of each dual field is the sum of two, where one of the fields covers the skin of the lower part of the body from the feet to the abdomen, on which the reference point is localized, and the other covers the skin from the abdomen to the fingertips. [1,9,10]. The source-patient distance used in this method is 300cm.

In case of the rotary method, irradiation is performed with one field (the gantry of the accelerator is positioned on the horizontal axis) [4,8]. The size of the cross section of the irradiation beam determined in the area of the patient's setup is 250×250cm. During irradiation the patient is rotated automatically, at a constant speed, around the vertical axis of the body. It is possible to use a distance between the radiation source and the patient equal to 300cm if a special filter equalizing the dose distribution (placed in the collimator and adjusted individually to the medical accelerator) and a Plexiglas board (approx. 20cm from the patient's body) are used. If the filter is not used this technique requires a very long source – patient distance (approx. 800cm) [4]. The nominal energy of the electron irradiation in both methods is 6MeV [1,4,8].

Aim

The method for total skin electron radiotherapy, based on the concept of the combined six dual field method and the rotary method, used in the Great Poland Cancer Centre was described in this work.

Materials and Methods

Irradiation scheme and the structure of therapeutic beams

During recent years, total skin electron radiotherapy has been performed in the Great Poland

Cancer Centre in the cases of 15 patients. In this method, the patient was placed on a rotary platform, 300cm from the source, and was rotated during irradiation around the vertical axis of the body. The time taken for complete rotation was the same as the total time of irradiation. A linear electron accelerator, a Clinac 2300 CD (Varian Company), was used as the radiation source. The rotary platform was connected to the accelerator because simultaneous start up of the platform and the accelerator was necessary, also an immediate shut down of the platform may be necessary in the case of accelerator malfunctions.

To improve the homogeneity of dose distribution on the patient's skin, a 1cm thick Plexiglas board (size 240×80cm) was placed, 20cm from the patient's skin. The irradiation was performed with a dual field – a combination of two fields. The axes of the beams were positioned at an angle of +20° from the horizontal axis for the first field, and at an angle of –20° from the horizontal axis for the second field. The point where the two fields combined into the complete dual field on the skin was the reference area placed horizontally along the axis of the irradiation beam for the horizontally positioned accelerator gantry (Figure 1). The size of the dual field was 230×115cm. (horizontally). Figure 1 shows a scheme for the rotary dual method of electron radiotherapy, as elaborated by the author. In the figure, the patient is positioned on the rotary platform and the positions of the linear accelerator gantry (–20° and +20°) used in the dual field irradiation, are presented. The nominal energy of electron irradiation was 6MeV, this refers to the average energy delivered to the patient's skin at 2.8MeV and was calculated with the formula [11]:

$$E_{śr} = 2.33 \cdot R_{50} \quad (1)$$

where RP_{50} is the depth in the patient's body, at which a dose of 50% of the maximum is absorbed [6]. Dose rate was 2.5Gy/min (TSEI conditions).

The patient was irradiated four times a week, with breaks on Wednesdays, Saturdays and Sundays, using a dose fraction of 1.5Gy to a maximum dose of 36Gy. The total treatment time was approximately 6 weeks [1,3,6]. To decrease the dose to the lenses of the eyes to 6Gy, eye shields (lead coated in paraffin) were used from the beginning of therapy. When a dose of 20Gy is exceeded nail bed shields were used [1–3,6]. The surfaces of the skin, absorbing less than 80% of the dose administered during irradiation by the total

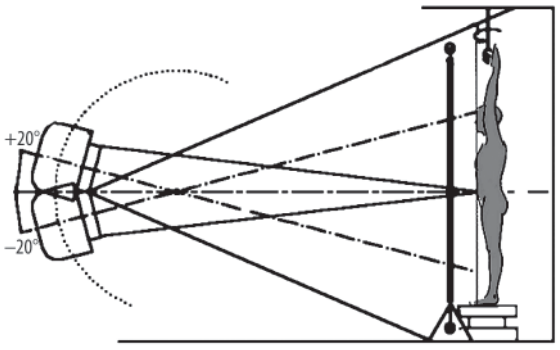


Figure 1. A schematic view of treatment geometry used during the rotary-dual method for total skin electron irradiation.

skin electron radiotherapy method were irradiated further with local fields [12–20], exceptions to this being the eye lids (under the shields), for which local fields were used only in case of histologically confirmed lesions, infiltrations and/or cutaneous tumours on their surfaces. During irradiation with additional fields, the patient was placed on the therapeutic table, at a source-surface distance of 100cm. A nominal energy of electron irradiation of 6MeV was used. When the patient is positioned on the therapeutic table at a distance of 100cm from the source, the depth of maximum dose absorption at an energy of 6 MeV e is 1.4cm. To decrease the depth to 4mm, at which the maximum dose in the skin is absorbed, 1cm thick flexible boluses were used. During the irradiation of the eye lids, the eye lids were protected with special lead shields.

Measurements and Results

Absolute dosimetry

To establish the dose distribution in the skin, and on its surface, it is necessary to determine the parameters and functions characterizing electron irradiation beams, of nominal energy 6MeV, which are used in the rotary dual method for total skin electron irradiation [6].

In order to establish the dose distribution in the skin (at different depths) it is necessary to determine the percentage depth dose (PDD) under stationary conditions (without rotation during irradiation) and under rotational conditions (with rotation during irradiation).

PDD is defined as the dose in the beam axis at optional depth d in a phantom – dose in the beam

axis at maximum depth as a percentage ratio according to the formula:

$$PDD = D_d/D_{max} \cdot 100\% \quad (2)$$

where D_d refers to the dose at optional depth d [mm] and D_{max} refers to the dose at maximum depth. Figure 2 and Table 1 show the percentage depth dose measured for rotational conditions (during rotation of a cylindrical paraffin–wax phantom of 15cm radius – second column in Table 1, solid line in Figure 2) and for stationary conditions (without rotation in a solid Plexiglas phantom – third column in Table 1 dashed line in Figure 2) by this technique. PDD was measured under stationary conditions using an ion chamber in a Plexiglas phantom, and under rotational conditions by means of dosimetric film placed between two cylindrical layers of paraffin–wax in a phantom 30cm in diameter. In order to take best advantage of the dosimetric film [21], a Lumiscan 50 PTW Freiburg densitometer was used to calibrate the optical film density for 6MeV electron energy and several doses. For 6MeV electrons there exists a linear relationship, between optical density OD and dose D (Gy), in the range of 0±0.20Gy (OD=3.5×D). Absorbed dose could be calculated from a calibration curve, up to an optical density of OD=2.5.

In both cases correction factors including those for water and differences in the thickness of phantom materials were inserted.

During the measurement of PDD, the source-phantom surface distance was 300cm, the gantry of the accelerator was placed in the horizontal axis of irradiation and the size of the field determined at the surface of the phantom was 115×115cm. Results of measurements were as follows: 1) the maximum dose depth (100% dose) under stationary conditions was 4mm, 2) contamination with photon irradiation, determined as PDD at a depth of 25mm, was 1%, 3) the depth receiving 80% of the maximum dose was 9.5mm, and 4) the depth receiving 50% of the maximum dose was 12mm. Under rotational conditions, the dose values were: on the surface – 100%, at a depth of 4mm – 83.5%, at a depth of 20mm – 2.0%.

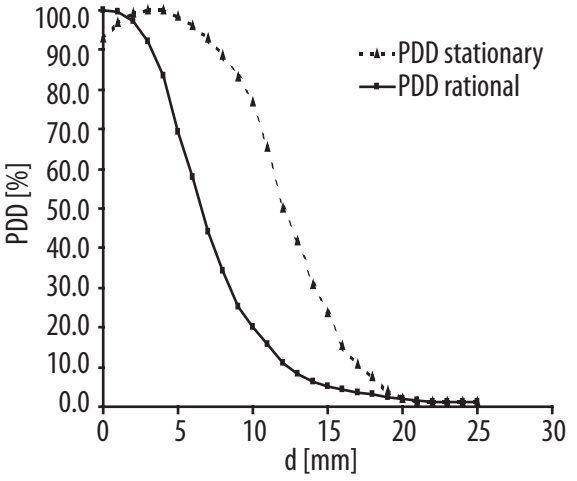


Figure 2. The percentage depth dose for stationary (dashed line) and rotational (solid line) conditions in the rotary-dual method for total skin electron irradiation.

Table 1. The percentage depth dose for stationary (PDDstac) and rotational (PDDrot) conditions in the rotary-dual method for total skin electron irradiation.

d [mm]	PDD_{rot} [%]	PDD_{stac} [%]
0	100.0	93.0
1	99.5	97.0
2	97.0	99.5
3	92.5	100.0
4	83.5	100.0
5	69.0	98.5
6	58.0	96.0
7	44.0	93.0
8	34.5	88.5
9	25.5	83.0
10	20.0	77.0
11	16.0	65.5
12	11.0	50.0
13	8.0	42.0
14	6.5	31.0
15	5.0	23.5
16	4.0	15.0
17	3.5	11.0
18	3.0	7.5
19	2.0	4.0
20	2.0	2.0
21	1.5	1.5
23	1.0	1.0
25	1.0	1.0

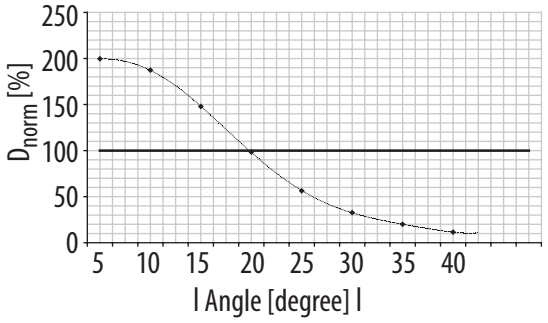


Figure 3. Dependence between the angles of two symmetrical fields in relation to horizontal axis creating a dual field and the dose measured in the air at the point of combination of fields.

Consecutive measurements of dose distribution were performed in order to establish the optimal set up of the gantry for the dual field (two fields, for which the gantry is set symmetrically to the horizontal axis), for which the dose at the reference surface area is equal to 100% of the dose. In case of the method applied in the Great Poland Cancer Centre, an ion chamber, of the Marcus type, was placed in the air, at the central point of the reference surface at the distance where the difference between the source and the measurement point is 300cm. Doses were measured while changing the angle of the radiation beam, relative to the horizontal axis, from ±5° to ±40°. Symmetrical positioning of the gantry in relation to the horizontal axis was used each case, thus: +5° and –5°, +10° and –10°, +20° and – +20° etc. In Figure 3 and Table 2 the relationship is shown between the angles of the irradiation axes for the two symmetrical fields, and their relationship to the horizontal axis, creating a dual field. Also shown is the method by which the dose was measured in the air at the point at which the fields combined. The dose D_{norm} was normalized to the dose for one field, for which the irradiation beam was in the horizontal axis. The formula:

$$D_{norm} = [(D_+ + D_-)/D_0] \cdot 100\% \qquad (3)$$

was used, where D_+ and D_- are the doses measured at the point of the combination of both fields, using a symmetrical setup of the gantry (in relation to the horizontal axis). D_0 was the dose measured at the point of dose combination for one field and corresponding to the horizontally set (positioned) radiation beam.

The relationship between the dose on the skin (the phantom surface) and alterations to the distance between the source and the measurement point is a parameter which must be determined and is based on dose measurements performed in the air at different distances (ranging from 240cm to 340cm) between the radiation source and the measurement point.

Table 2. Dependence between the angles of two symmetrical fields in relation to horizontal axis creating a dual field and the dose measured in the air at the point of combination of fields

Angle [degree]|	D_- [%]	D_+ [%]	D_{norm} [%]
0	–	–	100.0
5	100.0	99.5	199.5
10	94.5	93.0	187.5
15	73.5	74.5	148.0
20	49.5	49.0	98.5
25	28.5	28.0	56.5
30	16.5	16.0	32.5
35	9.0	11.0	20.0
40	6.0	5.5	11.5

To determine the dose distribution outside the axis of the radiation beam, measurements of dose distribution in the air along and across the axis of the irradiated field need to be conducted (for two fields, for which the accelerator gantry is set at the position of +20° and –20° in relation to the horizontal axis. The distance from the source to the measurement point was 300cm). Chosen doses along the axis of the irradiated field were: the reference surface – 100%, 40cm above/below the reference surface – 100%, 80cm above/below the reference surface – 90%, 100cm above/below the reference surface – 80% and 120cm above/below the reference surface – 68%. The doses were presented as percentage values, normalized to the value measured at the point of field combination, according to the formula:

$$D_{norm} = D_z/D_{zo} \cdot 100\% \qquad (4)$$

where D_z is the dose measured at distance z [cm] from the surface, along the irradiated axis, and where D_{zo} was the dose measured at the point of field combination.

The parameters described, and the functions characterizing ionizing radiation, were determined only once during the adjustment of the method to conditions in this particular Centre.

Standard dose rate was measured each time a patient was prepared for treatment. The measured standard dose rate needed to be verified twice (after the second and fourth weeks) during the treatment. Moreover it is recommended to verify the stability of the standard dose rate delivered during each fraction by placing an ion chamber with a build-up cap in the spoiler (to provide conditions for electron balance). Measurement of the standard dose rate (before treatment) should be performed in stationary conditions with a Marcus type ion chamber in a Plexiglas phantom, allowing for the differences in density between Plexiglas and water.

During the measurement of the standard dose rate in the Great Poland Cancer Centre, the source-phantom surface distance was 300cm, the gantry of the accelerator was positioned in the horizontal axis of irradiation and the size of the field defined for the phantom's surface was 115×115cm.

In-vivo dosimetry

In-vivo dosimetry performed during therapy with rotary dual fields allows for control of the dose distribution and also, if necessary, to determine the areas which should be additionally irradiated using local fields [11,14,22–24].

The basic method for *in-vivo* dose measurement in TSEI is thermo-luminescent dosimetry (TLD). Other authors have used thermo-luminescent detectors (CaF2: Mn TL-400, size: 3×3×0.4mm) placed between two thin Plexiglas plates. The thickness of the plates corresponded to 1mm of water (the differences in density between the Plexiglas and water were taken into consideration).

The plates, with TL detectors between, were used to protect the detectors from potential mechanical damage which may arise during treatment (during attachment to the patient's skin before the irradiation and during removal afterwards). The measurement depth, at which the TL detectors were placed during irradiation corresponded to the maximum depth of dose absorption in the patient's skin.

The TL detectors were calibrated using Marcus type ion chambers under TSEI conditions. *In-vivo* dosimetry was conducted during each fraction (four times weekly) in the first two weeks and twice weekly within the next four weeks. The first three patients were exceptions to this rule. *In-vivo* dosimetry was performed during each fraction within the complete treatment time (six weeks). The measurements were conducted at the 22 measurement points proposed by Antolak et al. [14] and at 12 measurements points proposed by other authors (altogether 43 measurement points). During each fraction, the dose was measured at 8 measurement points. Before irradiation all TL detectors were incubated for 1 hour at 400ºC and then for a further 3 hours at 100ºC [25]. Each TL detector was labeled for further identification. Two to three hours after irradiation, the absorbed dose was read, using a Harshaw 3500 reader. The temperature at which the detectors were read was 300ºC. The measured value was multiplied by an individual correction (calibration) factor determined during the calibration procedure for each TL detector, consecutively receiving values of measured doses. The results were saddled with a 3% error, as defined at the 95% confidence level (2SD).

In Table 3 dosimetry reports for rotary dual fields and doses for local fields for one of the patients treated in the Great Poland Cancer Centre are shown. The doses were presented as percentage values, normalized to the total dose (36Gy). In the first column the points of dose measurement are presented. In the second column – the average *in-vivo* dosage measured for rotary-dual fields is presented. In the third column – recommendations referring to doses delivered during additional irradiation of chosen areas of the skin, using local fields, are shown. In the fourth column – the percentage of the dose administered using local fields is presented and in the fifth column – the total dose, being the sum of doses administered during irradiation with rotary dual fields and local fields, is presented.

Discussion and Conclusion

According to the EORTC recommendations referring to total skin electron irradiation, the dose distribution in the therapeutic plan (at the skin surface) should range between 90–110% of the prescribed dose [3]. Maximum radiation contamination should not exceed 0.7Gy [1,3,6]. The source-skin distance should be within the range from 3m to 8m [3,9,19]. The depth to which 80% of the prescribed dose is delivered should not be less than 4mm. At a depth of 20mm the absorbed dose should not exceed 20% of that prescribed [3]. The nominal energy range during total skin irradiation should be from 4MeV

Table 3. A dosimetric report for a selected patient treated by the rotary-dual method in the Greater Poland Cancer Centre. Abbreviations in third column mean, respectively: Ele – Electron beams, 6MeV – nominal energy, 6Gy – total dose for local field, (2Gy × 3 days) – method of dose fractionation.

	1	2	3	4	5
	Measurement point	**Rotary-dual field mean dose [%]**	**Recommendations for the additional local fields**	**Local fields dose [%]**	**Total dose [%]**
1.	Hands front	84.0	Ele 6MeV, 6Gy (2Gyx3days)	16.7	100.7
2.	Hands back	91.2	Ele 6MeV, 4Gy (2Gyx2days)	11.1	102.3
3.	Scalp vertex	44.1	Ele 6MeV, 20Gy (2Gyx10days)	55.6	99.7
4.	Forearms	103.6	–	–	103.6
5.	Elbows	90.1	–	–	90.1
6.	Forehead	93.2	–	–	93.2
7.	Occiput	96.5	–	–	96.5
8.	Biceps	65.3	Ele 6MeV, 10Gy (2Gyx5days)	27.8	93.1
9.	Shoulders and lateral side of neck	44.6	Ele 6MeV, 18Gy (2Gyx9days)	50.0	94.6
10.	Neck front	92.9	–	–	92.9
11.	Neck back	95.7	–	–	95.7
12.	Upper back	99.8	–	–	99.8
13.	Axilla left	101.4	–	–	101.4
14.	Axilla right	103.2	–	–	103.2
15.	Upper thorax	91.9	–	–	91.9
16.	Anterior abdomen	92.6	–	–	92.6
17.	Right abdomen	103.7	–	–	103.7
18.	Left abdomen	99.6	–	–	99.6
19.	Lower back	102.9	–	–	102.9
20.	Hypogastrium	96.1	–	–	96.1
21.	Hip right	107.8	–	–	107.8
22.	Hip left	105.3	–	–	105.3
23.	Buttocks	105.6	–	–	105.6
24.	Perineum	36.1	Ele 6MeV, 20Gy (2Gyx10days)	55.6	91.7
25.	Thigh front	95.0	–	–	95.0
26.	Thigh right	106.0	–	–	106.0
27.	Thigh left	106.5	–	–	106.5
28.	Thigh back	102.5	–	–	102.5
29.	Thigh (inside area)	58.3	Ele 6MeV, 12Gy (2Gyx6days)	33.3	91.6
30.	Calves	96.5	–	–	96.5
31.	Tibia	94.5	–	–	94.5
32.	Feet top	106.7	–	–	106.7
33.	Feet soles	–	Ele 6MeV, 26Gy (2Gyx13days)	72.2	72.2
34.	Fingers	54.6	Ele 6MeV, 18Gy (2Gyx9days)	50.0	104.6

Table 4. A comparison of the times needed for treatment realization by three described methods.

1	2	3	4	5	6
Method	**Prescribed dose**	**No of fields**	**Irradiation time t_{irr}**	**Verification time t_{ver}**	**Total time $t_{irr} + t_{ver}$**
Rotary-dual method (as applied by authors)	**1.5Gy**	**1**	**2×1.75min = 3.5min**	**2×3min = 6min**	**9.5min**
Six dual fields method*	1.5Gy	6	6×1.75min = 10.5min	6×3min = 18min	28.5min
Rotary method	1.5Gy	1	12.5min	3min	15.5min

* In six dual field irradiation, a full fraction dose (1.5Gy at all skin surface) was delivered for two days (three dual fields per day).

to 8MeV [1,3,6,9]and the total dose prescribed for skin surface during treatment (6–9 weeks) should range from 31Gy to 40Gy [3].

Parameters used by other authors (in the literature) were as follows: nominal energy – 6MeV, mean energy at the skin surface – 2.8MeV, PDD values (at the skin surface - 100%, at 4mm – 83.6% and at 20mm – 1.8%), SSD – 300cm, field size equal to 230cm by 115cm, fractional doses – 1.5Gy, the total time of treatment varied from 6 to 7 weeks and was compatible with EORTC recommendations.

The application of the rotary-dual method for total skin electron irradiation allowed us to reduce values such as the SSD distance, relative to that in irradiation by the rotary method. For example, the fraction irradiation time for the cylindrical phantom of 30cm dimensions was 3.5min for the rotary-dual method but 12.5min for the rotary method. The dimensions of most therapeutic rooms are usually too small to realize total skin electron irradiation methods with SSD distances greater than 350cm. Patient positioning and rotation during irradiation (based on the rotary method [4]) allowed a reduction in the number of dual fields used in the Stanford method from six fields to one dual field (rotary-dual method). This modification leads to a time reduction in set-up verification. For example, the mean time dedicated to set-up verification for one position or field is 3min, and the total time for the Stanford method amounts to 18min. In Table 4, a comparison of times needed for the realization of treatment by the three described methods is shown.

The results presented for *in-vivo* dosimetry (Table 3) in selected patients treated in the Greate Poland Cancer Centre confirm the need for application of additional local fields for areas of perineum, scalp vertex, hands, neck-shoulders and feet.

Weaver et al. [23] suggested that height is a key factor in determining the dose to the scalp vertex, occiput, elbows and hands. Our data [26] and data published by Antolak el al. [2] support this suggestion. Moreover, a correlation between obesity index and some localizations at the patient's skin such as the shoulders, axillae, fingers, upper thorax, anterior abdomen, lower back, lateral abdomen, groin and great toe has also been reported. These results indicate that the total dose prescribed for additional fields depends on both height and obesity and should be prescribed individually for each patient.

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