Dose Measurements in the Treatment of Mycosis Fungoides with Total Skin Irradiation using a 4 MeV Electron Beam

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INTRODUCTION

The total skin irradiation (TSI) is one of the most efficient techniques in the treatment administered with curative intent of the cutaneous T-cell lymphoma (mycosis fungoides). The cure may be obtained in 10% to 40% of the cases [13]. To irradiate all skin in an appropriate time of the machine, in most times, are used large electron fields with treatment distances about 3 meters.

The original Stanford University technique [4], created in 1960, in which they irradiated the patient in all longitudinal extension, was applied in a 4.8 MeV linear accelerator, that provided 2.5 MeV electrons in the patient, by the use of 4 couple beams with the patient placed in front of the beam, 3 meters distant from the accelerator.

In this work we describe a 4 MeV electron beam treatment method based on Stanford technique, where we used a Varian linear accelerator CLINAC 2100. We intend to improve the uniformity of the dose and to reduce the treatment time to the patient and also to reduce the problems with the overlapping treatment fields that occurs in conventional treatment that uses 1 meter of focus-skin distance.

For this method the patient is placed on a rotative base and he assumes successively 6 positions: stand up and perpendicular to the beam, distant 2.83 meters from the source, with 60 degrees of interval between the rotations. In each position, the patient is irradiated by a couple of beams (the beam angulation is 19.5 degrees above the transversal axis in the middle of the patient and 19.5 degrees below it), figure 1a. A rotatory base makes easier the rotation of the patient, figure 1b.

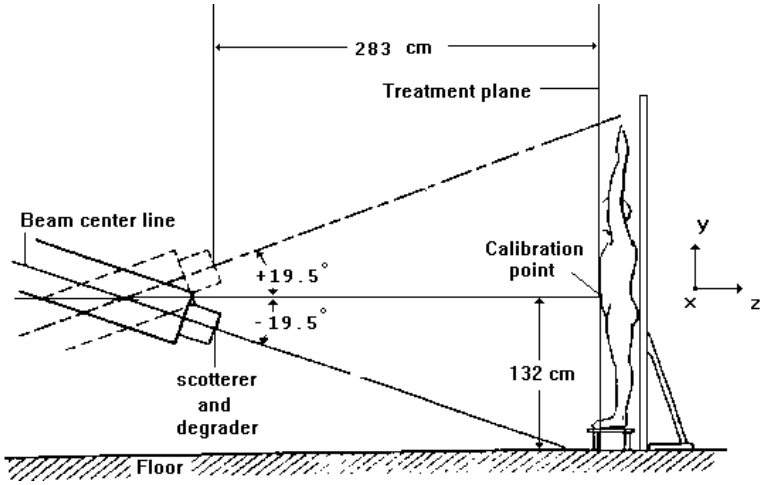

Figure 1a. Geometrical arrangement of the symmetrical dual-field [3].

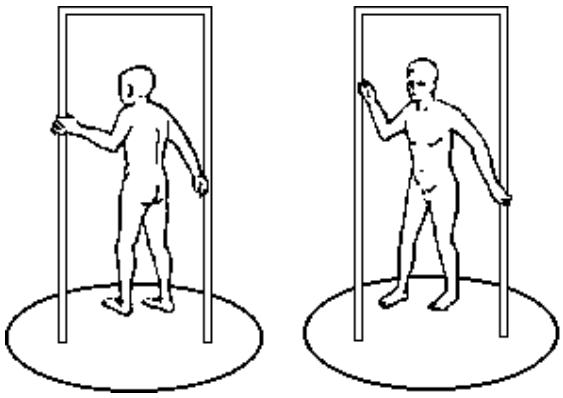

Figure 1b. Patient position for two of the angled dual-field exposures [3].

MATERIALS

A Farmer chamber and a parallel plate ionization chamber were used to measure the relative depth dose. The electrometer used with these chambers was a Standard Imaging, type: CDX-2000. Table 1 presents the main characteristics of the chambers.

Table 1. Ionization chambers characteristics

Manufacturer		N.E.	PTW
Type		Thimble - "Farmer"	Parallel plate - "Markus"
Serial number		2505/3	w23343
Nominal volume (cm^3)		0.6	0.055
Wall material and thickness (g/cm^3)		Graphite - 0.065 g/cm^3	PMMA [b] - - - -
Buildup cap and thickness (g/cm^2)		PMMA - 0.551	PMMA - 0.500
Internal radius (mm)		3.15	---
Electrode	Diameter (mm)	---	5.3
	Material	Aluminium	Graphite polystyrene
	Spacing (mm)	---	2
Window	Material	---	Graphite polyethylene foil
	Thickness (mg/cm^2)	---	102
Guard ring width (mm)		---	0.2
K_m		0.982	---
K_{att}		0.992	---
N_k^{ref} (mGy/div)		41.426 [a]	---
$N_{D,ar}^{ref}$ (mGy/div)		40.76	---

[a] Chamber calibration factor given in air kerma units, measured by Calibration Laboratory at IPEN/CNEN-SP.
[b] PMMA: Polymethyl methacrylate.

Dosimetric films, Kodak type X-Omat V, were used to measure the relative depth dose, the dose distribution in the treatment plane and to check the dose distribution in all thickness of interest, placing them into the anthropomorphic phantom.

Two phantoms were used to simulate tissue: a plastic water plane plates phantom and an antropomorphic phantom. Its characteristics are given in table 2.

Table 2. Phantoms[c] characteristics

Type	Plastic water plane plates (30 x 30) cm^2	Anthropomorphic type: SBU-4 Phantom (kyoto, Japan) (trunk)
Material	White polystyrene	Human skeleton, encapsulated in tissue equivalent plastic
Density	1,060 g/cm^2	Equivalent plastic: 1,06 g/ml
C_{pl}	0,981 [d]	---

[c] Materials composition in Reference 14.
[d] Obtained in Reference 7.

Thermoluminescent dosimeters of LiF (TLD-100, 3.1 x 3.1 x 0.9 mm^3) from Harshaw Bicron were used to in vivo measurements of the absorbed dose on patient skin surface. The TL dosimeters were evaluated in a Harshaw TLD model 5500.

METHODS

Measurements of the relative depth dose

The beam quality determination in the plane of the patient was performed as follows: a parallel plate ionization chamber was placed in the air, at the field center perpendicular to the beam, distant 283 cm from the focus and then irradiated with a 4 MeV electron beam. Solid water plates were placed in front of the chamber and changing the plate thickness, it was obtained the percentual variation of absorbed dose as function of depth in solid water. This method was repeated using a farmer chamber as well dosimetric films, figure 2 [5,10,11,12].

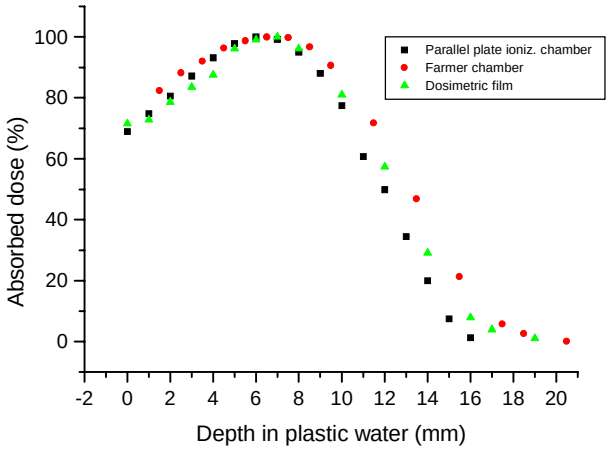

Figure 2. Relative depth dose for the 4 MeV electron beam in the treatment distance.

Calculations of the most probable energy in the treatment plane

From the parallel plate ionization chamber curve in figure 2 it was obtained the value of the practical range Rp. Using this value in the following equation it was obtained the most probable energy at the phantom surface:

$$E_{p,0}[MeV] = 0.22 + 1.98R_p + 0.040(R_p)^2$$

where R_p= 1.63 cm in water. Therefore $E_{p,0}$ = 3.55 MeV.

Dose distribution in the treatment plane

The beam homogeneity with two angled fields ± 19.5° in relation to the patient's waistline was verifyed placing dosimetric films in the vertical and, horizontal axis of the treatment plane. The horizontal direction of the plane has a variation of ± 4% in 40 cm width and, the vertical plane has a maximum value about 14% at the center of the patient and a dose variation of ± 6.5% along 150 cm of its vertical axis, figures 3a and 3b, respectively.

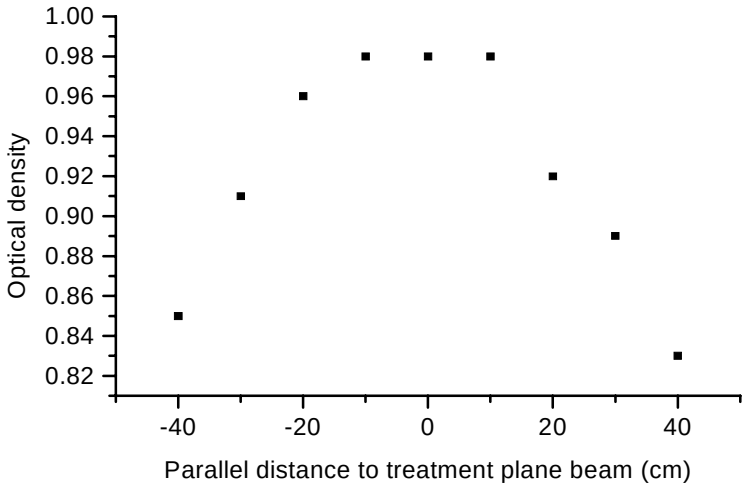

Figure 3a. Field flatness in the treatment horizontal plane.

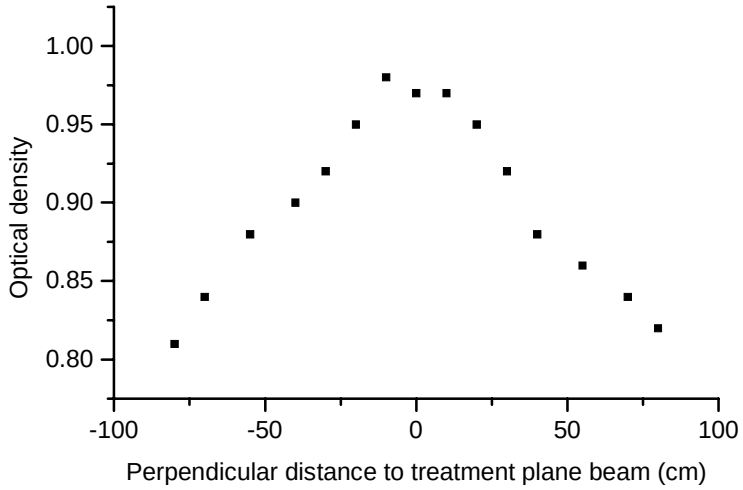

Figure 3b. Field flatness in the treatment vertical plane.

Parallel-plate ionization chamber calibration factor

To use the parallel-plate chamber in the determination of the absolute values, it was necessary to calibrate it, that means, determine its response to an exposure or exposure rate of a known one, involving the use of at least a standard instrument. For so much, the parallel plate chamber was calibrated by comparison with a Farmer chamber (described in the table 1) previously calibrated at the calibration laboratory of IPEN/CNEN. The intercomparation was accomplished with a 16 MeV electron beam, as described by AAPM Protocol Report No.39, figure 4 [1]. The choice for this energy is recommended to decrease the perturbation effect in the reference chamber cavity under the reference depth [6,7,8].

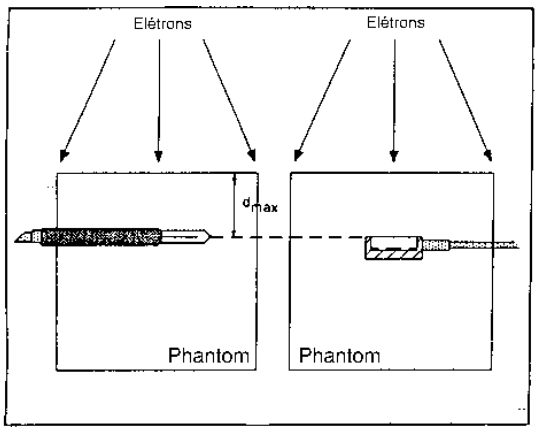

Figure 4. Geometry used to calibrate the parallel-plate chamber (right) with the Farmer chamber (left).

For this measurements it was used a Farmer chamber and a parallel-plate chamber and their respective electrometers described in the table 1. The conditions for the measurements were: pressure 693 mmHg, temperature 22.7 Celsius degrees, field size 10 x 10 cm and distance focus-surface 100 cm. The measures were performed to a 16 MeV electron beam build-up depth, that correspond to 2 cm of plastic water.

The ratio between the reading obtained from both ionization chambers Mref/Mx was 11.65. The parallel plate chamber calibration factor can be calculated using this value and the equation 2.

$$N^{x}_{D,air} = N^{ref}_{D,air} \cdot \frac{M^{ref}}{M^{x}} \cdot \frac{P^{ref}_{wall} \cdot P^{ref}_{cav} \cdot P^{ref}_{cel}}{P^{x}_{wall} \cdot P^{x}_{cav} \cdot P^{x}_{cel}} \qquad (2)$$

where: M^{ref} and M^{x} are the average values obtained from the Farmer chamber and the parallel plate chamber, respectively. They were corrected for pressure and temperature, ions recombination and the polarity effect, that was despicable; $P^{ref}_{wall} = 1$ for Farmer chamber under a electron beam; $p^{ref}_{cav} = 1 - 0.02155 r e^{-0.1224\overline{E}_z} = 0.947$ [7]; $P^{ref}_{cel} = 0.998$ for the aluminium central electrode; $p^{x}_{wall} \cdot p^{x}_{cav} = 0.978$ [14]; $P^{x}_{cel} = 1$ for the parallel plate chamber. $N^{ref}_{D,ar} = 40.76 mGy/div$ is the Farmer chamber calibration factor obtained from Calibration Laboratory at IPEN/CNEN-SP.

Substituting these data in equation 2 the parallel plate chamber calibration factor under the electron beam is obtained: $N^{x}_{D,ar} = 45.89 cGy/div$.

Calculation of the absorbed dose to the phantom by a single electron beam

The absorbed dose in water for the radiation beam in subject (Q), in a depth reference z, is $D_{w,Q}(z_{ref})$ [4]:

$$D_{w,Q}(z_{ref}) = M_Q \; N^{pp}_{D,air} \; (\overline{s}_{w,air})_Q \; (p_{cav} p_{wall})_Q \qquad (3)$$

where $M_Q = L \; f_{p,t} \; p_s \; h_m$, is the mean value obtained of the electrometer per monitor units of the accelerator ($\overline{L}/MU = 0.4531/300 = 1.5 \times 10^{-3}$) with corrections for room pressure and temperature ($f_{p,t}$=1.10), for ions recombination (p_s = 1) and fluency of the electrons in the water in relation to plastic water phantom (h_m = 1.0193); stopping power ratio for electrons from water to air, $(\overline{s}_{w,air})_Q$ = 1.055 [8]; $(p_{cav}p_{wall})_Q$ = 0.978 for parallel-plate chamber in a electron beam; and $N^{pp}_{D,air}$ = 46.08 cGy/div as calculated in equation 2. Substituting the data in equation 3 the absorbed dose value is obtained, $D_{w,Q}(z_{ref})$ = 7.96E-2 cGy/MU.

Calculation of the absorbed dose in the phantom due to the six pairs of electron beam

The absorbed dose in the phantom due to the 6 pairs of beams, D(6p), may be expressed in terms of the number of the monitor units set for a single horizontal beam, M_h, as follows [2,3]:

$$D(6p) = M_h D_{w,Q}(z_{ref})R(1p:1h)R(6p:1p) \quad (4)$$

where $D_{w,Q}(z_{ref})$ is the calibration factor for a horizontal beam, that is, the absorbed dose per monitor unit delivered on the central axis, its value is 7.96E-2 cGy/MU; R(1p:1h) is the ratio of the dose delivered by one angled pair of beams to that delivered by one horizontal beam, and its value is 1.084; R(6p:1p) is the ratio of the dose delivered to an anthropomorphic phantom by the full total-skin electron therapy treatment (by the six angled pairs) to that delivered by one angled pair, its value is 1.954.

To determine R(1p:1h) it was used the parallel plate chamber, table 1, in the build-up depth (6 mm of plastic water phantom) and the Farmer chamber with equilibrium electronic cap put in the waist line of the anthropomorphic phantom. The nominal dose rate of the accelerator was 400 MU/min. To measure a pair of beams, the gantry was angled ± 19.5 degrees in relation to the patient center.

To determine R(6p:1p) it was used the Farmer chamber with equilibrium electronic cap placed in the waistline of the anthropomorphic phantom. The nominal dose rate of the accelerator was 400 MU/min. To measure the absorbed dose in the phantom by the six pairs of electron beams, the gantry was angled ± 19.5 degrees in relation to the patient center and the anthropomorphic phantom was rotated six times, 60 degrees of intervals; and to measure the contribution caused by a pair of electron beam the gantry was angled ± 19.5 degrees in relation to the patient center, the Farmer chamber was irradiated in each angulation of the gantry.

Substituting the values measured, $D_{w,Q}(z_{ref})$, R(1p:1h), R(6p:1p), in equation 4 and using 100 cGy for D(6p), the dose prescribed by the physician to irradiate the total skin of the body, we can have the value of M_h, the number of the monitor units set for a single horizontal beam, its value is 593 MU for each electron beam.

Cumulative dose due to the X-ray component

The X-ray dose from the six pair of beams was measured with a parallel plate chamber placed into the plastic water phantom in two positions: in the build-up depth and 15 cm depth. The measurements were performed at the distance of treatment (283 cm from the focus), the chamber was irradiated with a 4 MeV electron beam; the nominal dose rate of the accelerator was 400 MU/min. The ratio between these measurements was 2.5% of ionization produced in the build-up depth, that mean that the X-ray dose from the six pairs of beam produces an increase of 2.5% in the skin dose.

Dose distribution checked with dosimetric films and TLD

The treatment simulation using the antropomorphic phantom with a film placed between two sections shows a satisfactory dose distribution. Figures 5a, 5b, show two films put into the phantom in a transversal section of skull and abdomen (waistline). Figure 6, shows respectively the graphics representation of dose variation with the depth.

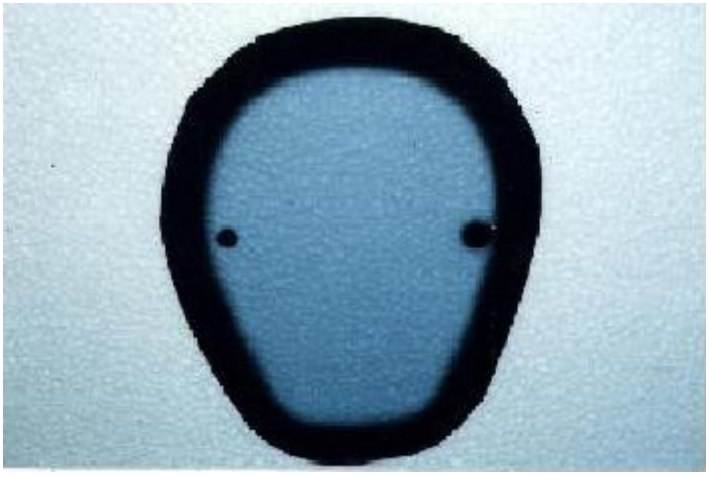

Figure 5a. Film placed into the phantom in a transversal section of skull.

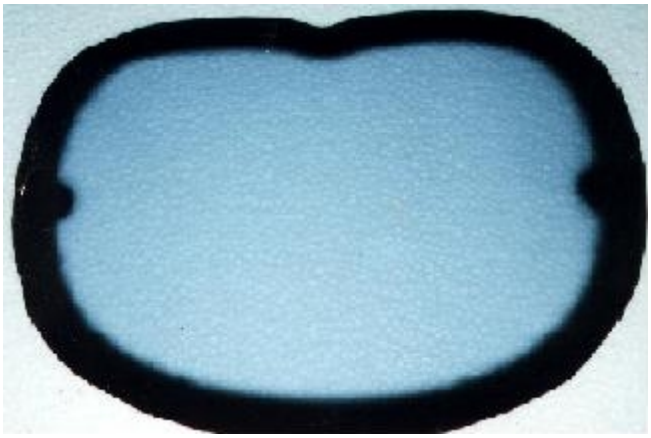

Figure 5b. Film placed into the phantom in a transversal section of waistline.

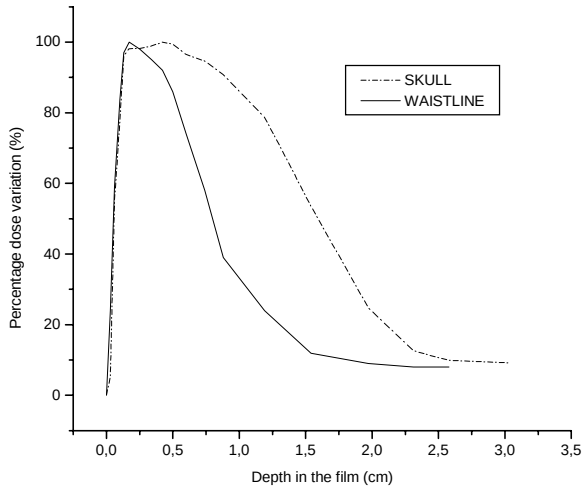

Figure 6. Relative depth dose presented by the dosimetric films placed into the antropomorfic phantom.

The absorbed doses were studied in some patient regions by *in vivo* measurements with LiF thermoluminescent dosimeters [5], and the results were: (i) the feet presents an increasing of approximately 50% of the dose, being placed out from the field during the half of the treatment, (ii) the vertex of scalp presents a decreasing of 6.5% of the dose and (iii) intergluteus (perineum) presents a decreasing of about 30% until 40% of the dose. The internal sides of the thigh are sub-dosed regions too. After clinical evaluation, these sub-dosed regions receives a complementary radiation dose in localized fields and the over-dosed regions were protected with cerrobend blocks put in front of the beam for that specific region.

Conclusion

The early reactions observed after total-skin irradiation are: dry skin, pain in toes and fingers, very small hematological variation, skin hyperpigmented and the late reactions are: uneven pigmentation, skin fragility, subcutaneous fibrosis and alopecia.

The experimental results shown that independently of the stage of the disease this kind of treatment can be always indicated. Its main advantages are: reduced time for treatment, less than 20 minutes; homogeneity of the skin dose at interest deepness (from about 4 mm to 8 mm); the X-rays contamination was according with recommended by AAPM Report nº 23 [3]; low treatment cost.

The delivered doses in the patient were measured with thermoluminescent dosimeters placed on skin surface and compared with those done with dosimetric films placed an anthropomorphic phantom. The dose distribution in the films shows a good uniformity, according with AAPM Report nº 23 [3], in all thickness of

interest as seen in figures 5a and 5b, so it is possible to use this technique in the treatment of the mycosis fungoides as well Kaposi's sarcoma.

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