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Original Contribution

TOTAL BODY IRRADIATION WITH A 10 MV LINEAR ACCELERATOR IN CONJUNCTION WITH BONE MARROW TRANSPLANTATION†

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Total body irradiation (1000 rad, single dose) in conjunction with chemotherapy and bone marrow transplantation is a therapy for acute leukemia. We show that a 10 MV linear accelerator is a suitable source of radiation for these procedures. Dosimetric and clinical results are presented for 25 patients who were treated between 5/76 and 12/78.

Total body irradiation, Bone marrow transplantation, Acute leukemia, 10 MV X-rays.

INTRODUCTION

Total body irradiation (TBI: 1000 rad, single dose) preceded by agressive chemotherapy and followed by bone marrow transplantation, is a treatment for acute leukemia. Most of the previous experience with this modality has been with Co-60 irradiation.[4,5]

Our center does not have a suitable cobalt-60 irradiator; however, we do have a 10 MV linear accelerator*, which can produce an adequate beam size for TBI of adults (diagonal full-width-half-maximum of 180 cm at 370 cm Source-Surface Distance (SSD)). To establish the suitability of 10 MV X-rays for TBI, we set the following dosimetric requirements: 1) dose uniformity ±5% to ±10%; 2) dose rate of 5 to 10 rad per minute at mid-depth; 3) a superficial dose equal to or greater than 90% of the midline dose; and 4) a detailed dosimetry record for each patient. Each of these requirements will be discussed in turn.

Accuracy of dose determination

1000 rad is the dose called for by the treatment protocol at our institution. The radiation serves a dual purpose: it is an adjunct to the chemotherapy in eradicating the malignant proliferative cells of the bone marrow and an immune-response suppressor to avoid rejection of the engrafted donor bone marrow. 1000 rad approaches published values[2] of doses that may result in death from acute gastrointestinal (GI) radiation syndrome. Therefore, it is important that the planned dose not be exceeded in the region of the GI tract. In certain non-critical areas, such as the extremities, dose errors on the high side may not be consequential. Lung complications are a problem in bone marrow transplantation programs; however, dose limits for the lung are not yet established. We set a limit of ±10% of 1000 rad for dose accuracy and dose uniformity, with the goal to be ±5%.

Dose rate

Dose rates of about 5 rad/min leading to a total dose of 1000 rad have been demonstrated to be well tolerated in patients with regard both to immediate GI symptoms such as nausea, vomiting, diarrhea and to delayed effects, such as death from acute GI syndrome.[1] Higher dose rates are generally not considered to be well tolerated. However, Kim *et al*[3] discuss the biological equivalence of a lower dose with a higher dose rate (750 rad at 26 rad/min). We choose to limit the midline dose rate to less than 7 rad per minute.

Superficial dose

Since leukemic infiltrates may be found in the skin, it is desirable that the superficial dose (the dose to the first few millimeters of tissue) satisfy the same requirements of total dose as other locations. With 10 MV photons, the skin sparing effect (the superficial dose is 10–50% of the dmax dose) is not overcome by increased exit dose. Consideration must be given to increasing the superficial dose by means such as bolus applied to the skin.

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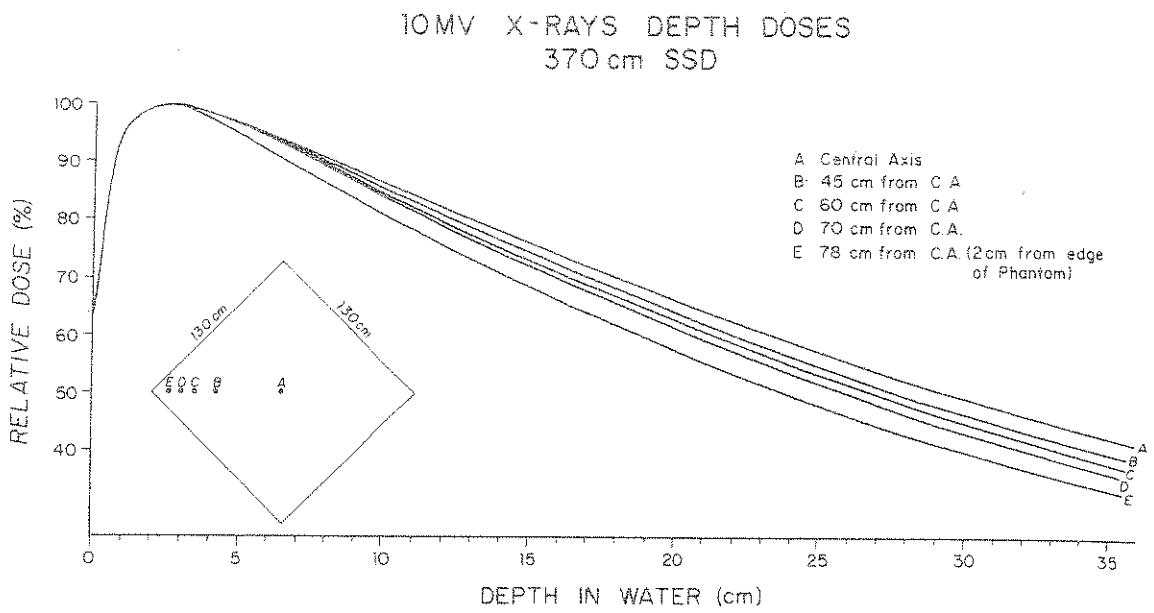

Fig. 1. Central axis and off-axis depth doses at 370 cm source-surface distance (SSD), 130 cm square field, 10 MV x-rays.

Dosimetry record

In order to accumulate meaningful clinical data, a dosimetric record must establish dose delivery and dose uniformity for each patient. It is important to be able to correlate dose with observed morbidity (including recurrence of leukemia). Others have reported on the use of thermoluminescent dosimetry (TLD) in the rectum and/or axillae to monitor dose.[4] We feel that a non-invasive dosimetric technique is indicated; therefore, we employ a system of externally applied TLD at multiple anatomic points to monitor dose accuracy and uniformity. The TLD system will be described in a later section.

METHODS AND MATERIALS

Preliminary measurements

The following measurements were taken in preparation for the TBI program (all involve a 130 cm square field at 370 cm SSD. A SSD of 370 cm was chosen because this was the maximum permitted by the construction of the room; 370 cm SSD is approximately 70 cm from the wall of the room toward which the beam is directed):

a) Central axis and off-axis depth doses at 370 cm SSD. Data were taken using a 40 × 40 × 40 cm water-filled radiation field analyzer*. The results and the points along the field diagonal at which measurements were made are shown in Figure 1.

b) Beam intensity profile at dmax at 370 cm SSD was measured using a 0.6 cc air ionization chamber at depth 2 cm in a 30 × 30 × 30 cm polystyrene phantoms. Comparable results were obtained using TLD with 2 cm buildup mounted on a plywood board. Since our experience has been that symmetry is maintained within ±2% by the linear accelerator's beam steering and dosimetric system, we averaged the results for either side of central axis, as shown in Figure 2.

c) Central axis depth dose in the build-up region (0 to 3 cm) was measured by means of a 0.3 cc thin window air ionization chamber† and by TLD ribbon, both in a 30 × 30 × 30 cm polystyrene phantom. Figure 3 shows the results of the measurements. For evaluation, the relative dose using 8 and 16 single layers of hospital blanket was measured.

Radiation dose uniformity

Measurements of midline dose were undertaken using a humanoid phantom** and TLD. A comparison of

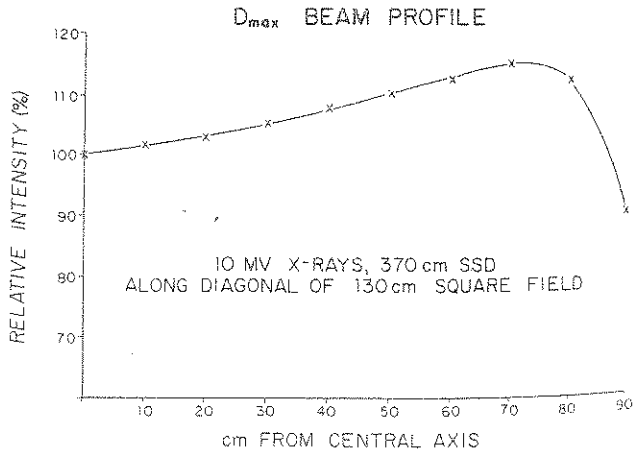

Fig. 2. DMAX beam intensity profile at 370 cm SSD, diagonal of 130 cm square field, 10 MV x-rays.

*Therados RFA-1.

†Nuclear Enterprises Model 2536/6.

**Alderson Rando Phantom.

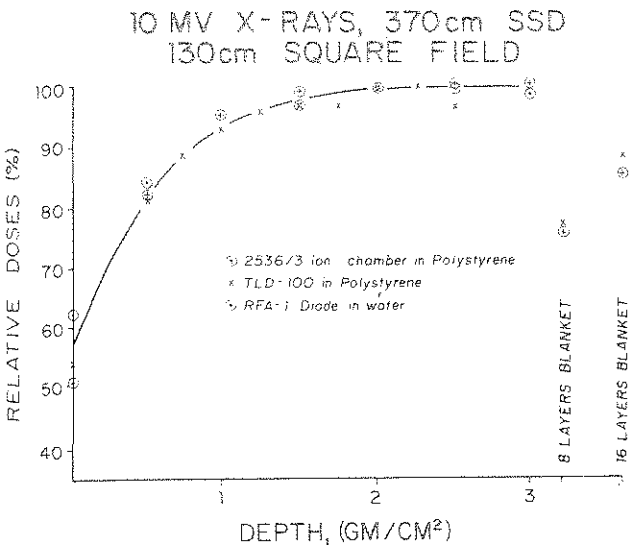

Fig. 3. Central axis depth doses in the build-up region for 130 cm square field, 370 cm SSD, 10 MV x-rays.

predictions based on calculations of output factor and depth dose was made with measurements.

$$\frac{\text{predicted dose off-axis midline}}{\text{central axis midline dose}} = \frac{\text{OPF} \times .\text{DD (oap)}}{.\text{DD (c.a.)}}$$

Where OPF is the off-axis output factor (Figure 2) and .DD is the fractional depth dose on the central axis (c.a.) or on a parallel axis passing through the off-axis point (Figure 1). Using the pre-drilled dosimeter holes in the phantom (the point closest to the midline was used), we placed TLD ribbons in gelatin capsules in the sections 1 through 34. The results are shown in Figure 4. The range of deviations from unity in parts per hundred of the ratio of the predicted and the measured midline dose was −11 to +5, while the mean of the absolute value of the deviation was 4.1 {standard deviation (S.D.) = 2.6}. We conclude that it is possible to use our measurements of depth doses and off axis factors to predict dose along the midline of the mid-sagittal plane to within ±5%.

Dose uniformity in a transverse plane for AP-PA irradiation was evaluated in two sections using TLD. No bolus was used to bring up the superficial dose in this series of measurements.

Sections 13 (chest with lungs) and 32 (pelvis) were used. Section 13 is at the level of the bifurcation of the bronchi. The S.D. of 26 points was 4% of the mean. For 12 points in lung tissue, the S.D. was 3% of mean and for 14 points in non-lung tissue, the S.D. was 1% of mean. The ratio of lung to non-lung tissue doses was 1.07. For Section 32, the uniformity of 48 points showed a S.D. of 4%. Two points at a depth of approximately 0.5 cm below the anterior surface were 10% below the average dose. Two points on the lateral surface at a depth of approximately .5 cm and 1 cm were 14% and 5% above the mean dose, respectively.

Conclusions from measurements

A. Need for beam-tissue compensation. Figure 4 reveals that measured doses are from 22 to 30% higher

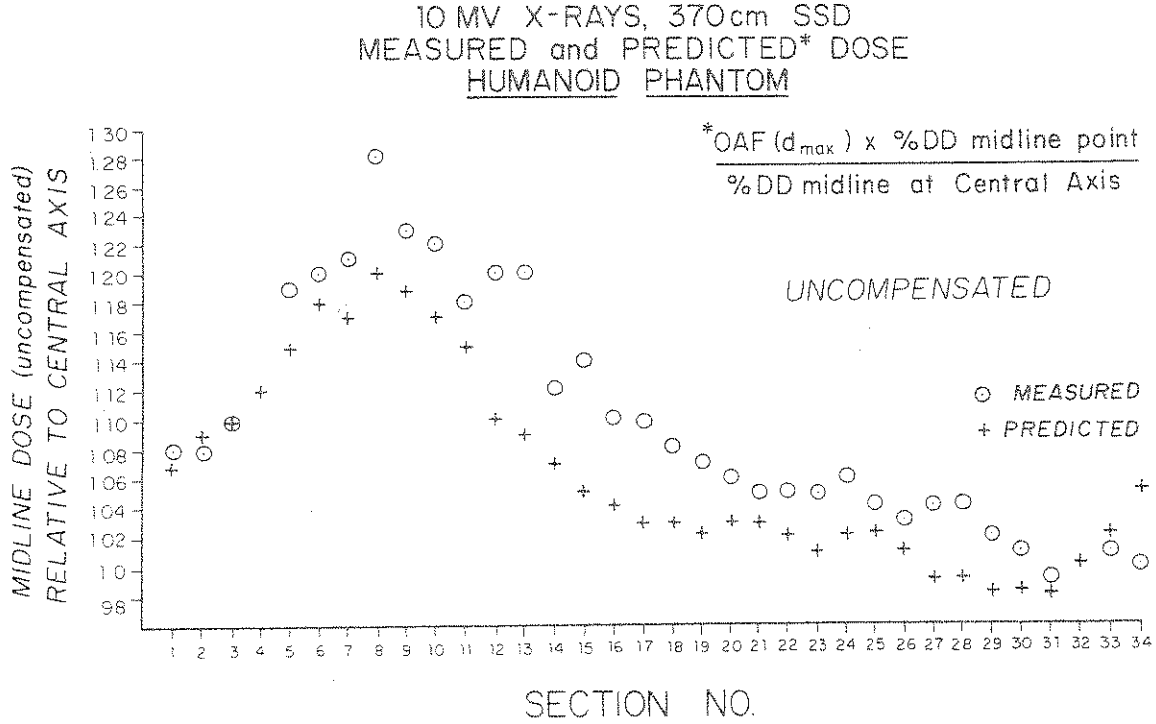

Fig. 4. Predicted and measured mid-line doses in phantom without beam compensation, 10 MV x-rays 370 cm SSD, 130 cm square field. Central axis at section 32. OAF, DD, see text for explanation of terms.

than the midline dose on the central axis which is in the region of the pelvis. The region of high dose is in the upper mediastinum, upper lung and neck. Acute doses of 1300 rad in these areas most likely would lead to unacceptable morbidity. Therefore a compensating filter is necessary to reduce the non-uniformity to an acceptable level.

B. Superficial dose-bolus. By summing the entrance and exit dose and comparing with the midline dose for AP-PA treatment, it can be shown that the superficial dose varies from 26% to 31% lower than the midline dose for patient thicknesses of from 8 to 30 cm. At the depth of 0.5 cm, the doses are 12% to 13% lower than the midline dose; at a depth of 1.0 cm the doses are approximately 6% lower than the midline dose. To insure that any infiltrates of tumor cells into the superficial layers of skin receive a dose within 10% of the midline dose of 1000 rad, we must add bolus material to the patient equivalent to 0.8 cm of tissue. Our approach has been to use hospital blankets, which the patients tolerate very well and appreciate in the cool treatment room. As shown in Figure 3, 16 single layers of blanket are equivalent to approximately 0.8 cm. Rather than covering the face with blankets, we place a 0.6 cm transparent lucite sheet in front of the patient's face during AP irradiation.

C. Dose uniformity. The measurements in the transverse sections of the phantom show that the dose uniformity is adequate at all depths (provided bolus is used for superficial depths). The agreement between predicted and measured mid-depth doses on and off the central axis as shown in Figure 4, show that the combination of off-axis output factors and off-axis depth doses can provide the basis for the design of a compensating filter to produce adequate mid-depth dose uniformity.

Beam filter design—Patient measurements and computations

The previous sections have shown that measurement of the patient's anterior-posterior thickness at various points along the cranial-caudal axis, coupled with measurements of beam intensity profile and fractional depth dose, can be used to calculate the midline dose without compensation at those points relative to the midline dose at the central axis of the beam. The computations reveal the amount of attenuation required in a beam intensity filter to produce a uniform midline dose.

We bring the patient to the department about one week before the scheduled TBI to obtain measurements required for the filter design. This visit also serves as an introduction to the procedure, the equipment, and the personnel. The procedure is explained in detail. The treatment is simulated while the patient is on a padded gurney located against the east wall of the accelerator treatment room. The collimator jaws are opened to the fullest extent and the collimator is rotated so that the diagonal of the field is parallel to the floor and coincident with the mid-saggital plane of the patient. The gurney is adjusted to give an SSD to the pelvic area of 370 cm and the patient is adjusted so that all areas of the body are no less than 10 to 20 cm from the edges of the light field. The upper portions of the body are usually flat (SSD within 4 cm of 370 cm); however, the knees must be flexed somewhat to bring the body within the light field. Marks are placed on the patient at the beam center and at several other points. The anterior-posterior thicknesses at these points are measured and recorded, along with the distances of the points from the central axis.

These parameters are used for beam filter design and the marks are used to reposition the patient as required

Table 1. Physical data and beam parameters for a patient (UPN 15)

Position	Distance from beam center	Half-thickness +0.8 cm	Fractional depth-dose .DD	Off-axis factor OAF	Desired transmission, T
Central axis (pelvis)	0	11.3	.835	1.00	1.00
Umbilicus	13 cm N	10.8	.84	1.02	.975
Xiphoid process	30 cm N	11.3	.828	1.05	.960
Suprasternal notch	49 cm N	7.8	.90	1.10	.843
Base of chin	61 cm N	(6.3)	.93	1.13	.795
Center forehead	75 cm N	10.3	.813	1.14	.899
Top of head	78 cm N	(10.3)	.800	1.13	.924
Mid-thigh	14 cm S	9.3	.875	1.01	.945
Knees	32 cm S	6.8	.925	1.05	.860
Mid-calf	48 cm S	6.3	.93	1.08	.831
Mid-foot	73 cm S	4.3	.97	1.11	.776
Tip of feet	86 cm S	(4.3)	.97	.90	.957

Notes: 0.8 cm is added to midline depth to account for the 16 layers of blankets covering the patient. Numbers in parentheses are thicknesses used for regions where thickness is changing rapidly. Fractional depth dose measurements are either central axis or off-axis values as appropriate, normalized to the depth of maximum dose (approximately 2 cm).

Table 2. Beam filter design: Patient (UPN 15) 370 cm SSD, 65 cm SDD

Position	Distance from central axis	Demagnified distance	Desired* transmission	Calculated No.** of thicknesses	Arbitrary† judgement
Central axis (pelvis)	0	0	1.00	0	0
Umbilicus	13 cm N	2.3 cm	.975	0.5	0
Xiphoid	30 cm N	5.2 cm	.960	0.8	0
Suprasternal notch	49 cm N	8.6 cm	.843	3.2	2
Base of chin (upper neck)	61 cm N	10.7 cm	.795	4.3	3
Center of forehead	75 cm N	13.1 cm	.899	2	1
Top of head	78 cm N	13.6 cm	.924	1.5	1
Mid-thigh	14 cm S	2.4 cm	.945	1.1	1
Knees	32 cm S	5.6 cm	.860	2.8	2
Mid-calf	48 cm S	8.4 cm	.831	3.5	3
Mid-foot	73 cm S	12.8 cm	.776	4.8	3
Tip of feet	86 cm S	15.0 cm	.957	0.8	0

*See Table 1.
**Number of thickness of 0.11 cm lead sheet = $[\ln T]/[-0.48] \div 0.11$.
†See text.

during the treatment session. Table 1 shows the physical data and beam parameters for a typical patient, *U*nique *P*atient *N*umber (UPN) 15, a male 18 years of age, who reported his height to be 165 cm. From Table 1, one can see that attenuations of up to 20% or more are required in relatively thin portions of the anatomy such as the neck and feet.

Beam filter construction

It is well established that tissue compensator design is strongly a function of treatment depth and field size; for that reason, universal compensation to achieve uniform dose at all depths and all regions of the radiation field is not strictly achievable. At the beginning of our total body irradiation program, we chose a naive approach to

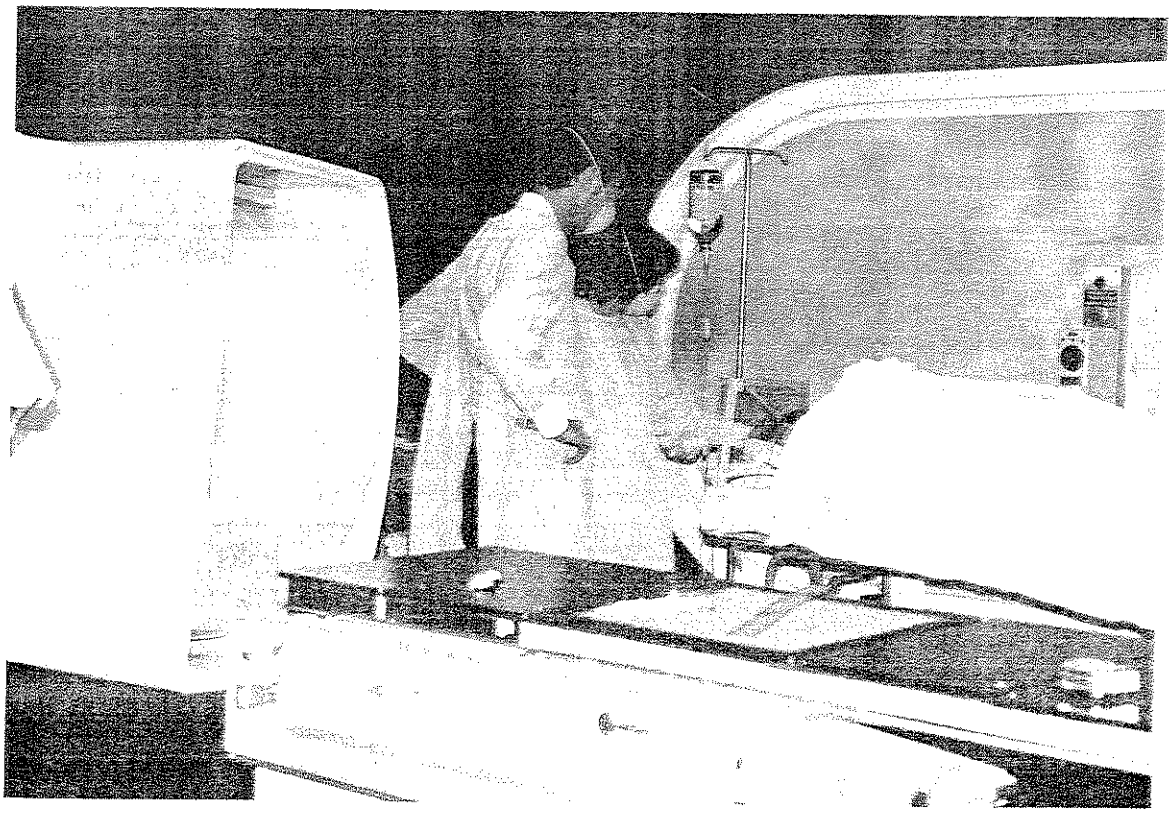

Fig. 5. Patient in position for anterior-posterior radiation.

compensation that seems to yield acceptable results. We obtained a supply of sheet lead with a nominal thickness of 0.11 cm, which easily can be cut to shape with ordinary scissors. Using a measured linear attenuation coefficient of 0.48 cm^{-1} one can show that each added thicknesses of lead results in approximately a 5% reduction in intensity. Using the points and transmission values in Table 1 as a guide, we construct the beam filter on a plastic tray, which fits into the blocking tray holder at a source-to-tray distance (SDD) of 65 cm. Dimensions on the patient's surface are demagnified by the ratio 65/370 in constructing the filter. Table 2 shows the results of calculations for beam filter design for the anatomic positions shown in Table 1. The final column in Table 2 is the result of our experience with the initial patients in the program that there was overcompensation in the regions above the mid-mediastinum and below the knees. For those regions we arbitrarily reduce the calculated number of thicknesses by 1 for values of 3 or 4; in the region of the calf and below we use no more than 3 thicknesses of lead so that any errors are in the direction of higher rather than lower dose. The width of the strips is 10 cm. They are assembled along the diagonal of a solid lucite block tray using double-stick adhesive tape.

Calculating monitor units setting

The number of monitor units to deliver a midline dose of 1000 rad is calculated from the measured dmax output of the linear accelerator at 370 cm SSD with the filter tray in place, using the fractional depth dose for the patient's mid-thickness on the central axis of the beam. As an example, for patient UPN 15, the computation was:

$$\text{Monitor units for 1000 rad} = \frac{1000 \text{ rad}}{(0.0786 \text{ rad/mu})\,(0.835)} = 15237 \text{ mu}$$

where 0.0786 rad/mu is the dmax output of the machine at 370 cm SSD and 0.835 is the fractional depth dose of 11.3 cm. The output rate of the linear accelerator is adjusted to 100 monitor units per minute, so the midline

Table 3. Clinical results

Unique patient number	Type of acute leukemia	Age (yrs)	Outcome of BMT (3/79)	Unique patient number	Type of acute leukemia	Age (yrs)	Outcome of BMT (3/79)
1	AMMOL	29	Died day +61 with recurrent leukemia	18	ALL	8	Died day +38 with recurrent leukemia
3	AMMOL	18	Died day +252 with GVHD and CMV pneumonia	19	AML	39	Alive and in CR 14 months p. BMT
4	AML	51	Died day +61 with recurrent leukemia	22	AML	54	Died day +26 with acute respiratory failure
5	AML	34	Died day +34 with recurrent leukemia	23	AUL	29	Alive and in CR 10 months p. BMT
6	AMOL	28	Alive and in CR 27 months p. BMT	24	ALL	14	Alive and in CR 9 months p. BMT
9	ALL	29	Alive and in CR 25 months p. BMT	25	AMMOL	20	Died day +10 with hepatic failure
10	ALL	7	Died day +65 with recurrent leukemia	26	ALL	21	Died day +51 with GVHD and CMV pneumonia
11	APL	30	Alive and in CR 23 months p. BMT	27	AML	25	Alive and in CR 7 months p. BMT
13	APL	33	Died day +78 with GVHD and CMV pneumonia	28	AML	32	Died day +15 with acute cardiac failure
14	ALL	17	Died day +138 with recurrent leukemia	29	ALL	20	Alive and in CR 6 months p. BMT
15	ALL	17	Alive and in CR 18 months p. BMT	31	AML	32	Alive and in CR 4 months p. BMT
16	AML	36	Alive and in CR 16 months p. BMT	32	AMMOL	15	Alive and in CR 3 months p. BMT
17	AUL	23	Died day +61 with GVHD and CMV pneumonia				

AML = Acute myeloblastic leukemia.
AMMOL = Acute myelomonocytic leukemia.
AMOL = Acute monoblastic leukemia.
ALL = Acute lymphoblastic leukemia.
APL = Acute promyelocytic leukemia.
AUL = Acute undifferentiated leukemia.
CR = Complete remission.
CMV = Cytomegalovirus.
GVHD = Graft vs host disease.
Note: Missing numbers (except UPN 2, who died prior to BMT), are patients with diseases other than acute leukemia.

dose rate is approximately 7 rad per minute for a typical patient and the total irradiation time is in the order of 140 minutes.

Patient dosimetry

In order to verify the correctness of the beam filter construction and to provide a data base for evaluation of the treatment regime, we measure the dose at several anatomic locations for the complete treatment using TLD. TLD material with tissue-equivalent build-up are placed on the anterior surface of the patient at the chosen locations. The first 250 rad of the planned 1000 rad midline dose is delivered in the anterior-posterior direction while the patient is reclining on his/her side (Figure 5). After 250 rad has been administered, the patient is turned, leaving the dosimeters in position, and an additional 250 rad is administered in the posterior-anterior direction.

At the end of the first 500 rad total midline dose, the dosimeters are removed and replaced with fresh TLD. Irradiation continues for an additional calculated 250 rad in the PA direction, while the dosimeters are readout and compared with a set of dosimeters exposed to 500 rad under calibration conditions. Since patient UPN 26, the procedure has been modified so that the initial set of TLD are readout following the administration of a precalculated 250 rad midline dose (125 rad AP followed by 125 rad PA). The purpose of the change was to provide an earlier adjustment to the monitor units or compensating filter. In approximately 50% of the patients treated, a change is made as a result of the TLD measurements. The most common changes are the addition or deletion of the filter material in the region of the upper mediastinum or the forehead. The TLD doses measured in the procedure described above are actually a combination of entrance and exit doses and not a direct measurement of mid-line dose. However, using depth dose data, one can show that the midline dose is approximately 3% higher than the sum of the dmax (AP) and exit (PA) doses recorded by TLD on the anterior surface for typical patient thicknesses (8–30 cm).

RESULTS

Between May 1976 and December 1978, 26 patients with acute leukemia were entered into our bone marrow transplantation (BMT) program. 25 were actually trans-

Table 4. TBI dosimetry results - 5/18/76 to 12/5/78

Unique patient number	Date	Pelvis, beam axis	Center forehead	Mid foot	Umbilicus	Xiphoid	SSN	Thigh or knee	Calf or lung	Mean (rad) of all points (± SD/ mean × 100)
1	5/18/76	1018	925	804	NA	931	NA	1099t	NA	955 ± 12%
3	7/27/76	991	922	971	NA	NA	NA	NA	NA	961 ± 4%
4	8/24/76	953	916	944	964	941	NA	NA	NA	944 ± 2%
5	9/28/76	1044	970	973	1050	NA	981	NA	NA	1004 ± 4%
6	12/28/76	977	940	951	NA	914	1008	NA	NA	958 ± 4%
9	3/01/77	1017	936	1015	977	NA	956	NA	NA	980 ± 4%
10	3/24/77	1002	986	997	NA	1002	1037	1012k	NA	1006 ± 2%
11	5/10/77	982	957	1042	NA	NA	1136	1055k	NA	1034 ± 7%
13	7/12/77	1082	1048	1024	NA	NA	1059	1122k	NA	1067 ± 4%
14	8/09/77	1003	1035	984	NA	872	1043	961k	NA	983 ± 6%
15	9/27/77	975	963	1009	NA	934	916	1037k	NA	972 ± 5%
16	11/01/77	973	1035	952	NA	1090	1081	948k	NA	1013 ± 6%
17	11/15/77	1013	976	1049	NA	877	973	1044k	NA	989 ± 6%
18	12/13/77	957	1008	980	NA	954	1042	NA	1062L	1001 ± 4%
19	1/31/78	1021	1032	1038	1076	1014	1102	998t	1118L	1050 ± 4%
22	4/25/78	1033	954	1034	988	919	1021	1000t	939L	986 ± 4%
23	6/06/78	1097	1069	1096	1061	1001	1088	956t	1214L	1073 ± 7%
24	6/27/78	1019	902	999	1000	1063	909	1001k	NA	985 ± 6%
25	7/12/78	1022	883	1100	NA	1005	971	1010t	1115L	1015 ± 8%
26	8/08/78	931	945	938	978	871	1094	922t	877L	945 ± 7%
27	8/29/78	931	912	934	945	981	886	929t	NA	931 ± 3%
28	9/12/78	987	883	961	977	1005	940	921t	863L	942 ± 5%
29	9/27/78	1008	938	889	940	870	986	899t	930c	933 ± 5%
31	11/28/78	1023	936	946	999	1010	946	952t	994c	976 ± 4%
32	12/05/78	999	1019	846	973	953	978	957t	911c	955 ± 6%
		n = 25	n = 25	n = 25	n = 13	n = 20	n = 22	n = 11	n = 7L	n = 25
Mean (rad)		1002	964	979	994	960	1007	968	1027	986
S.D. (rad)		40	53	69	43	64	69	57	135	40
% DIFF 1000		+0.5	−4%	−2%	−1%	−4%	+1%	−3%	+3%	−1%

NA = data not available.

planted (UPN 2 received chemotherapy and died of pneumonia two days prior to TBI). The various types of acute leukemia as well as the patients' ages are presented in Table 3. TBI was preceded by administration of two different regimens of high dose chemotherapy: the first ten patients received cyclophosphamide 60 mg/kg five and four days before TBI; the next sixteen patients received cytosine arabinoside 5 mg/kg eight and three days and cyclophosphamide 80–100 mg/kg five days before TBI. Bone marrow was obtained from the histocompatible allogeneic donors by multiple needle aspirations[6] and transfused into the recipients between four to six hours after TBI was completed. Engraftment was confirmed in all 25 transplanted patients using various genetic and clinical markers. The outcome of BMT is described in Table 3; 12 of the 25 transplanted patients were alive and in continued unmaintained complete hematological remission 3, 4, 6, 7, 9, 10, 14, 16, 18, 23, 25, and 27 months after BMT. More detailed clinical information is being prepared for publication. For the 25 patients treated between 5/18/76 and 12/5/78, th modal of value of midline dose uniformity at all anatomi cal sites was 4% (Range ±2% to ±12%). The mean dos was 986 rad. Results are summarized in Table 4.

DISCUSSION

It has been our experience that a 10 MV linear accelerator is an effective tool for delivering a satisfactorily uniform dose. The 10 MV linear accelerator provides an inherently more uniform dose than cobalt-60 because of its higher depth doses, and the problem of skin sparing is easily overcome by using a simple bolus. The dose rate from a linear accelerator is easily controllable and remains constant from patient to patient, without variation attendant to source decay and without changes in irradiation geometry which would be made to compensate for source decay. Simple tissue compensators are adequate to provide dose uniformity. TLD, externally applied, provide a non-invasive means for monitoring radiation dose accuracy and uniformity.

REFERENCES

1. Cassady, J.R., Order, S., Camitta, B., Marck, A.: Modification of gastrointestinal symptoms following irradiation by low dose rate technique. *Int. J. Radiat. Oncol. Biol. Phys.* **1:** 15–20, 1975.
2. Hall, E.J.: *Radiation and Life*. Oxford. Pergamon Press. 1976, pp. 46–47.
3. Kim, T.H., Kessey, J., Sewchard, W., Nesbit, M.E., Kiwit, W., Levitt, S.: Total body irradiation with a high-dose-rate linear accelerator for bone marrow transplantation in aplastic anemia and neoplastic disease. *Radiology* **122:** 523–525, 1977.
4. Miller, R.H., Langdon, E.A., Tesler, A.S.: Total body irradiation utilizing a single ^{60}Co source. *Int. J. Radiat. Oncol. Biol. Phys.* **1:** 549–552, 1976.
5. Thomas, E.D., Buckner, C.D., Banajai, M., Clift, R.A., Fefer, A., Flourney, N., Goodel, B.W., Hickman, R.I., Lerner, K.G., Neiman, P.E., Sale, G.E., Saunders, J.E., Singer, J., Stevens, M., Storb, R., Weiden, P.L.: One hundred patients with acute leukemia treated by chemotherapy, total body irradiation, and allogeneic marrow transplantation. *Blood* **49:** 511–533, 1977.
6. Thomas, E.D., Storb R.: Technique for human marrow grafting. *Blood* **36:** 507–515, 1970.