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The Bone Marrow Dose in Tele-Radiotherapy in Japan

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遠隔照射治療による骨髄線量について

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（昭和45年2月9日受付）

昭和37年度における放射線治療，ＲＩ診療による骨髄線量及び同有意線量についての研究を行なつた．頻度及び被曝線量より遠隔照射による寄与以外は無視できたので，遠隔照射による骨髄線量及び同有意線量について，昭和37年10月より12月までの全国各施設における頻度種類を調査したカードをもとに，平均余命，骨髄分布などを求めた後１年間の線量を推定した．

それによれば骨髄線量は一年間一人当り 172g-rads (220mrem) となり，又同有意線量は62g-rads (79.4mrem) となつた．

Introduction

Among the effects of ionizing radiation, the deleterious one has been extensively studied by many radiologists in the world from the viewpoint of protection from radiological exposure. In 1958 the International Commission on Radiological Protection recommended to reduce the maximum permissible dose for occupational exposure and this revision was apparently due to the accumulated knowledges on the potential hazards of irradiation to man.

In the deleterious effect of ionizing radiation, the genetic and somatic injuries can be distinguished. The latter is further subdivided into the short- and long-term effects. The long-term effect of ionizing radiation is more important at the level of the maximum permissible dose than the short-term effect which munifects itself only at much higher level of exposure.

It is widely accepted that irradiation to bone marrow is the most influential to production of the long-term effect. "Bone marrow dose" is also considered as being closely related to "radiation induced leukemia significant dose". Leukemia, however, has many factors to be induced and such factors have been not fully clarified yet at present.

Our present investigation is concerned with the determination of "bone marrow dose" in patients with tele-radiotherapy based upon morphological examination on distribution of active bone marrow in man and measurement of absorbed radiation dose to the active bone marrow.

Most of bone marrow dose in patient with tele-radiotherapy is contributed from irradiation during the radiotherapy. The function of the bone marrow dose contributed from other source such as X-ray examination or clinical use of radioisotopes has been also investigated but the result of the above investigation will be reported in separated articles.

To calculate the bone marrow dose and bone marrow significant dose, we apply the following formula

$$D = \frac{\sum_j \sum_k (N_{jk} \cdot d_{jk})}{\sum_k N_k}$$

$$D_s = \frac{\sum_j \sum_k (N_{jk} \cdot d_{jk} \cdot L_{jk})}{\sum_k N_k}$$

where

D: bone marrow dose

Ds: bone marrow significant dose

N: number of individuals

d: bone marrow dose per individuals

j: exposure dose class

k: age class

Members

In accordance with the actual working fields, the group was further divided into four main subgroups as follows;

a) Survey group
b) Anatomical group
c) Physical group
d) Dose estimation group

The survey group collected the data related to "N_{jk}" by survey card method. The special designed cards were sent to all medical facilities where tele-radiotherapeutic apparatus and/or small sealed source and/or medical radioisotope laboratory were installed. The anatomical group investigated the distribution and quantity of active marrow in man by morphological and biochemical examination. The physical group measured absorbed dose at the various points in mannequin phantom where active bone marrow was distributed. The dosimetry was made for the irradiation techniques which were reported in the survey-cards. The dose estimation group put estimated bonemarrow dose data supplied from other groups and, in addition to its own consideration on "d" and "L", calculated the bone marrow dose and bone marrow significant dose by IBM computer of ABCC in Hiroshima.

Surveys

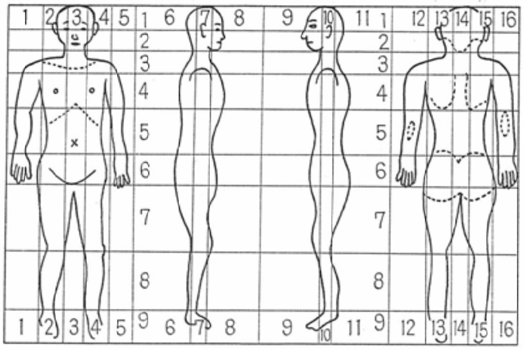
In consideration that such nation-wide surveys as this mightshed light on the present status of radiotherapy in Japan, it was proposed that the additional items to be surveyed which were not essentially relavant to the present investigation but were supposed to interest radiotherapists in Japan. Some of them

1. This sheet is for one patient, one technique, on field.
2. Don't fill up the part*
3. Don't mistake the survey cards because there are three kinds of cards: 1. for teletherapy (white) 2. for enclosed radioisotope (yellow) and 3. for radioisotope solution (red).
4. Enclose the numerals printed, fill up by numerals in blank and check by literatures or marks in other parts.

*Management		*Hospital Number	Sign
Hospital	Prefecture	Department 1. Radiology 2. Gynecology	5. Surgery 6. Dentology
Name	1. male 2. female Age	3. Otorhinolaryngology 4. Internal medicine	7. Dermatology 8. Others
Length cm	Weight kg	Clinical Metastases	
Diagnosis		1. remote metastases 2. regional metastases 3. regional and remote	4. no metastases 5. uncertain

Date of Therapy (enclose the date of therapy)
(Oct.) 20.21.22.23.24.25.26.27.28.29.30.31. (Nov.) 1.2.3.4.5.6.7.8.9.10.11.12.13.14.15.16.17.18.19.20.21. 22.23.24.25.26.27.28.29.30.(Dec.) 1.2.3.4.5.6.7.8.9.10.11.12.13.14.15.16.17.18.19.

Position of Irradiation	Field Size	1. on skin cm ×	cm or cmφ
		2. on tumor cm ×	cm or cmφ
			= cm^2
			= cm^2



A　For teletherapy (white)

1. X-ray	2. Radioisotope	3. Others
tube voltage kvp	source 1. Co-60, 2. Cs-137	1. betatron
tube current mA	3. Radium, 4. Others	2. lineac
additional filter mm Cu mm Al	curies or rhm	3. others
half value layer mm Cu	time min. sec.	
time min. sec.		
dose rate r at cm		

Maker and type of the Apparatus

Technique of irradiation 1. fix, 2. tangential, 3. rotation, 4. pendel, 5. Chaoul, 6. others

for 1 and 2　focus-skin distance　cm, air dose　r,
or focus-tumor distance　cm, skin-tumor distance　cm, tumor dose　r.

for 3　focus-center distance　cm, skin-center distance (mean)　cm, center dose　r.

for 4　focus-center distance　cm, angle　degree, skin-center distance (mean)　cm.
center dose　r.

for 5　focus-exit distance　cm, exit dose　r.

for 6

B　For small sealed source (yellow)

1. Source: Ra, Rn, Au-198, Co-60, P-32, Sr-90, Cs-137, Ta-182, others.
2. Sheath: Pt, stainless, gold, brass, vinyl, others.
3. Form: tube, needle, wire, button, adhesion, others.
4. Technic: intratumoral, intracavity, attatch, abstand, others.
5. Dose　mCi, hCour,
6. Organ

C　For radioisotopes (red)

1. Source: I-131, I-125, Au-198, Lu-177, Fe-59, Fe-55, Cr-51 P-32, As, others
2. Form: inorganic, organic, colloid, others.
3. Technic: oral, intravenous, peritoneal, pleural, cavitary, local, others.
4. Premedication
5. Dose: μCi, mCi.
6. Uptake and effective half life .
7. Organ

Fig. 1. Survey card designed for teletherapy

Table 1.Number of medical facilities in Japan and the results of survey.

		University hospital				Hospital				Practitions			
No.	Prefocturo	A	B	C	D	A	B	C	D	A	B	C	D
01	Hokkaide	2	2	2	2	420	63	52	37	2066	18	0	0
02	Aomori	1	1	1	1	87	13	12	7	617	1	0	0
03	Iwate	1	1	1	1	85	7	6	5	714	4	3	2
04	Miyagi	1	1	1	1	130	18	11	6	919	6	0	0
05	Akita	0				59	12	11	8	584	4	2	2
06	Yamagata	0				60	16	15	13	683	2	0	0
07	Fukushima	1	1	1	1	110	13	11	7	961	2	1	0
08	Ibaragi	0				119	18	13	10	967	8	4	3
09	Tochigi	0				103	14	12	8	755	10	6	3
10	Gumma	1	1	1	1	74	12	9	7	920	3	1	0
11	Saitama	0				172	17	12	10	1252	0	0	0
12	Chiba	1	1	1	1	195	11	5	4	1258	8	0	0
13	Tokyo	17	17	17	12	606	88	57	45	9376	48	9	4
14	Kanagawa (ex. Yokohama-city)	0				115	18	16	13	1414	8	3	0
15	Niigata	1	1	1	1	106	18	15	13	1404	5	1	1
16	Toyama	0				81	11	9	8	653	3	1	1
17	Ishikawa	1	1	1	1	81	12	11	7	734	2	1	1
18	Fukui	0				56	7	6	1	493	10	3	0
19	Yamanashi	0				50	3	3	2	428	2	2	1
20	Nagano	1	1	1	1	140	18	12	7	1122	2	0	0
21	Gifu	1	1	1	1	102	12	9	4	947	3	0	0
22	Shizuoka	0				89	28	25	20	1514	12	2	0
23	Aichi (ex. Nagoya-city)	0				153	35	25	21	1311	10	1	0
24	Mie	2	2	2	0	114	17	14	9	865	3	0	0
25	Shiga	0				38	7	7	6	525	4	3	2
26	Kyoto (ex.Kyoto-city)	0				54	8	8	5	460	2	0	0
27	Osaka (ex.Osaka-city)	2	2	2	2	138	24	15	9	1816	12	2	1
28	Hyogo (ex.Kobe-city)	0				158	22	18	12	1813	4	2	2
29	Nara	1	1	1	0	45	2	2	2	510	0	0	0
30	Wakayama	1	1	1	1	43	6	6	3	734	2	0	0
31	Tottori	2	2	2	2	29	7	6	6	367	1	0	0
32	Shimane	0				45	9	9	7	647	5	1	0
33	Okayama	1	1	1	1	155	23	17	9	1112	3	0	0
34	Hiroshima	1	1	1	1	205	36	31	22	1589	21	6	5
35	Yamaguchi	1	1	1	1	135	25	21	16	1079	10	3	1
36	Tokushima	1	1	1	1	70	12	10	7	531	4	2	1
37	Kagawa	0				73	10	9	6	524	4	0	0
38	Ehime	0				82	14	14	10	843	11	3	1
39	Kochi	0				83	12	11	4	515	10	2	1
40	Fukuoka	3	3	3	1	286	50	43	25	2601	30	7	2
41	Saga	0				73	7	5	4	617	5	0	0
42	Nagasaki	1	1	1	1	123	15	13	11	951	1	0	0
43	Kumamoto	1	1	1	1	124	15	9	5	1161	12	1	1
44	Oita	0				70	15	12	9	813	14	4	3
45	Miyazaki	0				121	8	7	6	487	4	2	1

46	Kagoshima	1	1	1	1	148	13	12	6	1054	13	3	2
51	Yokohama-city	1	1	1	1	78	10	8	6	967	10	3	2
52	Nagoya-city	4	4	4	3	116	23	17	12	1110	20	2	2
53	Kyoto-city	2	2	2	1	99	13	9	7	1389	6	2	0
54	Osaka-city	4	4	4	3	198	36	31	22	2785	14	5	3
55	Kobe-city	1	1	1	1	75	11	9	8	1271	2	0	0
	Rocovery		78.0%				65.8%				48.4%		
			mean recovery 64.7%										

A: Total number of medical facilities

B: No. of medical facilities which have any abilities on radiation therapy and radioisotope diagnostics

C: No. of medical facilities which have the abilities on teletherapy

D: No. of medical facilities in group C, which answer to the survey

Answered cards

Teletherapy	18786
Small source therapy	2133
R.I. use in clinic	1880

which were considered to be valuable and to give the facilities little trouble to fulfil the primary purpose of the present investigation were decided to be investigated. Fig. 1 shows survey cards for tele-radiotherapy, and survey cards for small sealed source therapy and medical uses of radioisotopes are also designed surveyed in reasonable items as shown in the lower part of the figure.

The total number of facilities under investigation was less than a thousand, as shown in Table 1. The survey was performed to all the facilities during a period of one month between October 20 and December 19, 1962. The answer to the survey card was obtained from 68% of all facilities till the end of May of the following year, as shown in the table. The pressing cards were sent two to the facilities, from which no answer had been obtained.

Bone Marrow Distribution

The weight of bone marrow in each bone of man was measured in ten cadevours, as shown in Table 2. The bone marrow was then histologically devided into three components, viz, red marrow, yellow marrow and supporting structure and the cell fraction (weight of red and yellow marrow/ weight of bone marrow

Table 2. Weight of bone marrow in each bone

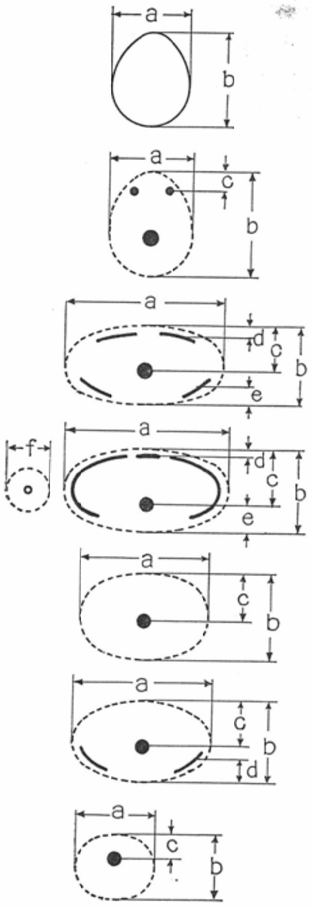
Case	26f	39f	34m	26f	29m	27m	33m	23m	41m	31m	mean
Cranium	—	—	—	—	—	—	148.3*	—	—	—	148.3
Mandib.	—	—	—	—	—	—	9.8*	—	—	—	9.8
V. cerv. (VII)	6.8	2.5	—	7.6	7.6	7.9	6.0	7.0	5.0	6.8	6.3
Clav. (d)	—	—	—	—	—	—	—	—	—	8.3	8.3
(s)	—	—	—	—	—	—	—	—	—	8.4	8.4
Humer. (d)	36.8	—	—	63.7	38.0	73.0	71.3	49.0	68.3	60.2	57.5
(s)	—	—	—	—	40.8	58.5	71.8	55.0	46.2	58.0	55.2
Scap. (d)	—	—	—	—	—	—	—	—	—	23.7	23.7
(s)	—	—	—	—	—	—	—	—	—	20.9	20.9
Cost (d) (V)	8.5	—	—	8.4	—	—	—	—	—	—	8.6
(VI)	—	5.0	5.9	—	8.1	9.0	7.8	8.3	11.6	13.7	
(s) (V)	7.5	—	—	—	—	—	—	—	—	—	8.5
(VI)	—	4.4	4.9	—	9.5	9.6	8.1	8.5	11.9	12.0	

Stern.	25.0	14.8	29.7	34.0	20.6	31.4	28.6	26.9	38.8	34.5	28.4
V. ther. (V)	8.9	—	—	12.6	—	—	—	—	—	—	10.8
(VI)	—	4.0	7.9	—	13.2	14.3	8.2	11.8	14.2	13.1	
V. lumb. (V)	18.5	11.5	22.0	24.1	22.6	20.9	22.0	29.0	33.2	25.3	22.9
Coxae (d)	71.8	—	67.5	126.1	70.0	130.0	129.1	145.0	164.0	128.6	114.6
(s)	91.0	56.7	—	—	94.0	144.0	122.9	100.0	153.0	133.4	111.8
Sacrum	74.5	39.4	61.7	81.9	80.0	99.6	94.1	125.0	106.3	103.3	86.6
Femur (d)	102.0	—	—	171.8	136.0	195.0	201.5	167.0	198.5	133.3	163.1
(s)	—	—	—	—	155.0	207.5	228.8	170.0	168.0	188.5	186.7
Ulna (d)	8.9	—	—	13.6	9.4	11.5	10.0	14.8	10.8	13.6	11.6
(s)	—	—	—	—	7.7	11.5	10.3	12.5	15.8	13.4	11.9
Radiu. (d)	6.9	—	—	13.1	7.3	11.5	13.1	14.2	20.1	12.9	12.4
(s)	—	—	—	—	9.1	8.8	12.7	12.8	15.1	12.7	11.9
Tibia (d)	59.0	—	—	105.8	76.0	138.0	107.0	123.0	133.0	76.0	102.2
(s)	—	—	—	—	95.0	112.0	109.0	122.0	142.0	102.8	114.0
Fibula (d)	7.7	—	—	17.5	10.7	14.3	16.4	13.6	19.0	10.5	13.7
(s)	—	—	—	—	10.8	13.1	16.9	12.0	18.1	12.3	13.9
Coccygis	—	0.2	0.5	—	—	—	—	—	—	—	0.4

*estimated

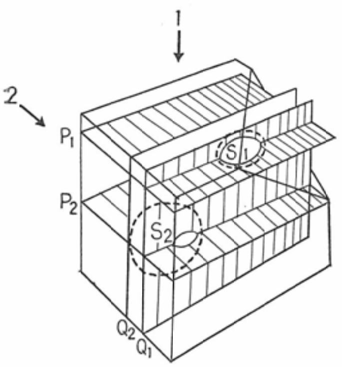
Table 3. Fractions in bone marrow and the weight of active bone marrow in each bone

	Total bone marrow	Fraction cells	Fraction active marrow	Active bone marrow
Cranium	148.3 (g)	0.5	0.75	55.61 (g)
Mandibula	9.8	〃	〃	3.68
V.Cervi.	6.3	0.7	1.00	4.41
Clavicula (d)	8.3	0.5	0.67	2.78
(l)	8.4	〃	〃	2.81
Scapula (d)	23.7	〃	0.75	8.89
(l)	20.9	〃	〃	7.84
Humerus (d)	57.5	〃	0.50	14.38
(l)	55.2	〃	〃	13.80
Ulna (d)	11.6	〃	0	0
(l)	11.9	〃	〃	0
Radius (d)	12.9	〃	〃	0
(l)	12.7	〃	〃	0
Costa (d)	8.6	0.7	1.00	6.02
(l)	8.5	〃	〃	5.95
Sternum	28.4	〃	〃	19.88
V. thorac.	10.8	〃	〃	7.56
V. lumb.	22.9	〃	〃	16.03
Coxae (d)	114.6	〃	〃	80.22
(l)	111.8	〃	〃	78.26
Sacrum	86.6	〃	〃	60.62
Coccygis	0.4	〃	0	0
Femur (d)	163.1	0.5	0.50	40.78
(l)	186.7	〃	〃	46.68
Tibia (d)	76.0	〃	0	0
(l)	102.8	〃	〃	0
Fibura (d)	10.5	〃	〃	0
(l)	12.3	〃	〃	0
			total	781.61



		mean σ (cm)	
Section 1.	a.	15.5 ± 1.3	At the middle of stirn. (Position 1)
	b.	18.6 ± 1.6	
Section 2.	a.	16.9 ± 0.8	At the middle of 4th cerv. vert (Position 2)
	b.	20.7 ± 0.5	
	c.	3.4 ± 0.3	
Section 3.	a.	30.6 ± 2.0	At the lower edge of clavicle (Position 3)
	b.	15.0 ± 1.1	
	c.	9.3 ± 1.0	
	d.	2.1 ± 0.6	
	e.	4.4 ± 0.6	
Section 4.	a.	30.3 ± 2.2	At the middle of 5th thor. vert. (Position 4)
	b.	16.8 ± 1.4	
	c.	10.9 ± 1.3	
	d.	1.3 ± 0.2	
	e.	3.4 ± 0.5	
	f.	8.5 ± 0.9	
Section 5.	a.	24.9 ± 1.3	At the middle of 2nd lumb. vert. (Position 5)
	b.	16.1 ± 1.5	
	c.	8.8 ± 1.5	
Section 6.	a.	26.4 ± 1.6	At the middle of 5th lumb. vert. (Position 6)
	b.	15.8 ± 1.7	
	c.	9.1 ± 1.4	
	d.	4.7 ± 0.7	
Section 7.	a.	14.7 ± 1.6	At the upper quadrant of femur (Position 7)
	b.	12.9 ± 0.7	
	c.	5.2 ± 0.4	

Fig. 2. Distribution of bone marrow in each position (Fig. 2).



S_1, S_2: actual distribution of bone marrow
P_1, P_2: mean distribution dimension of S_1 and S_2 assumed for calculation on direction (1).
Q_1, Q_2: mean distribution dimension of S_1 and S_2 assumed for calculation on direction (2).

Fig. 3. Explanation of assumed bone marrow distribution and bone marrow densities in the position.

as a whole) and the red marrow fraction (weight of red marrow/ weight of red and yellow marrow) were obtained as in Table 3. The spatial distribution of red marrow in the body was determined by use of cross-tomograms of seven representative cross-sections which are shown in Fig. 2.

In order to estimate the dose, the red marrow was assumed to be distributed uniform in the relevant volume about the point shown in Fig. 3. Bone marrow dose at each point was measured and the results are presented in Table 4 and 5.

Table 4. The representative position and bone marrow within the position

Position	Bone	Active bone marrow (g)	Projected area (cm²)	Active marrow density (g/cm²)
1–2, 3, 4	cranium	55.61	137	.406
2–2	mandibula-1/2	1.84	61	.030
2–3	cerv. vert. I-III	13.23	63	.210
2–4	mandibula-1/2	1.84	61	.030
3–2	clavicle (dex.)	2.78	85	.033
3–3	cerv. vert. IV-VII	17.64	71	.461
	thor. vert. I-II	15.12		
3–4	clavicle (sin.)	2.81	85	.033
4–1	humerus (dex.)	14.38	206	.070
4–2	scapula (dex.)	8.89	314	.258
	costa (dex.) I-XII	72.24		
4–3	sternum	19.88	88	.913
	thor. vert. III-XII	60.48		
4–4	scapula (sin.)	7.48	314	.252
	costa (sin.) I-XII	71.40		
4–5	humerus (sin.)	13.80	206	.070
5–3	lumb. vert. I-V	80.15	84	.954
6–2	coxae (dex.)	80.22	220	.365
6–3	sacrum	60.62	75	.808
6–4	coxae (sin.)	78.26	220	.355
7–2	femur (dex.)	40.78	452	.090
7–4	femur (sin.)	46.68	452	.103
1–6, 7, 8	cranium	55.61	160	.348
2–7	cerv. vert. I-III	13.23		
	mandibula-1/2	1.84	79	.215
	mandibula-1/2	1.84		
3–7	cerv. vert. IV-VII	17.64	150	.219
	thor. vert. I-II	15.12		
4–6, 7, 8	costa (dex.) I-XII	72.24		
	scapula (dex.)	8.89		
	sternum	19.88	456	.528
	thor. vert. III-XII	60.48		
	scapula (sin.)	7.84		
	costa (sin.) I-XII	71.40		
5–6, 7, 8	lumb. vert. I-V	80.15	174	.461
6–6, 7, 8	coxae (dex.)	80.22		
	sacrum	60.62	270	.811
	coxae (sin.)	78.26		
7–7	femur (dex.)	40.78	490	.178
	femur (sin.)	46.68		

Table 5. The active bone marrow density in each part

	1, 5, 12, 16	2, 4, 13, 15	3,14	6,11	7,10	8,9
1	.000	.406	.406	.348	.348	.348
2	.000	.030	.210	.000	.215	.000
3	.000	.033	.461	.000	.219	.000
4	.070	.258	.913	.528	.528	.528
5	.000	.000	.954	.461	.461	.461
6	.000	.360	.808	.811	.811	.811
7	.000	.097	.000	.000	.178	.000
8	.000	.000	.000	.000	.000	.000
9	.000	.000	.000	.000	.000	.000

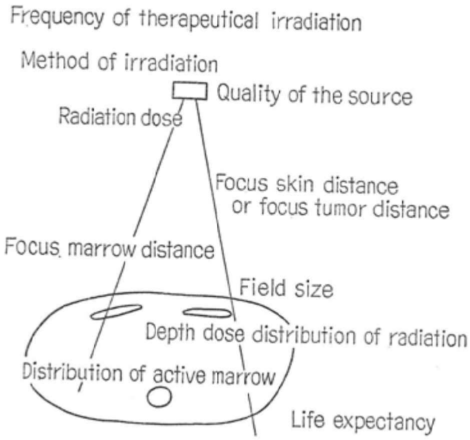


Fig. 4. Items which are needed for this research.

Table 6. Lists of used and dicarded cards

1.	fixed field	17,369	skin	14,975
			tumor	1,394
2.	tangential	689		
3.	rotation	253		
4.	pendel	336		
5.	chaoul	101		
6.	others	38		
	total	18,786		

Dosimetries

From the survey it became evident that the fixed field technique of irradiation was used in the majority of facilities under investigation. This fact played and important role to simplify the calculation of bone marrow dose in the present study.

As absorbed dose to each marrow cell in bone was impossible to be measured, dosimetry was carried out at each representative point in the phantom which had been decided by the former subgroup,using the representative qualities of radiation which had been also decided by the survey group,and the results are presented in Table 6. For determination of "d", the following formula was used.

Table 7. The pm-value in adults

Position / KV	1–$^{2}_{4}$	1–3	1–7	1–$^{13}_{15}$	1–14	2–$^{3}_{8}$	2–7	2–14	3–$^{2}_{4}$	3–3	3–7	3–$^{13}_{15}$	3–14	4–1	4–$^{2}_{4}$	4–3	4–6	4–7
<69	125	110	125	135	160	41	37	64	29	34	26	41	120	21	34	320	36	95
70– 89	230	220	230	270	320	82	73	128	58	67	52	82	240	42	68	640	72	190
90–109	283	273	284	324	382	98	86	152	80	92	70	96	265	52	84	720	88	234
110–129	335	326	337	400	460	112	102	183	108	135	96	118	305	66	108	830	110	290
130–149	398	390	400	476	545	128	116	222	140	164	124	140	350	80	128	900	130	345
150–169	460	456	463	540	628	142	131	235	172	200	153	158	390	93	150	1010	151	408
170–189	507	500	510	595	703	154	143	248	200	225	180	170	425	102	168	1100	168	465
190–209	553	545	557	628	767	166	153	257	240	248	194	172	450	110	177	1190	181	510
210–229	585	580	588	650	890	170	160	258	260	252	203	180	445	112	178	1200	180	515
230–249	590	583	594	660	798	170	161	260	265	257	208	180	442	113	175	1200	180	520
250–269	600	595	603	665	800	170	160	260	267	260	210	182	440	112	174	1180	179	515
173Cs	544	540	545	557	683	162	153	246	203	224	193	168	410	103	156	1142	157	506
^{60}Co	472	440	472	532	617	162	148	232	205	210	196	147	388	97	135	1230	139	488

Position / KV	4–8	4–$^{13}_{15}$	4–14	5–$^{2}_{4}$	5–3	5–6	5–7	5–$^{13}_{15}$	5–14	6–2	6–6	6–7	6–13	6–14	6–3	7–2	7–3
<69	73	35	300	19	70	110	20	35	313	32	130	85	155	425	110	20	7
70– 89	145	70	600	37	140	220	39	70	625	64	260	169	310	850	220	39	13
90–109	183	87	756	47	199	290	52	87	770	92	320	222	380	970	290	48	18
110–129	240	110	930	58	280	380	70	102	900	130	420	380	440	1120	400	62	26
130–149	300	132	1140	71	385	500	90	120	1060	180	550	342	510	1280	530	74	35
150–169	360	156	1320	84	500	620	108	132	1160	220	660	400	570	1450	670	85	44
170–189	410	175	1490	94	595	720	125	142	1260	260	740	447	600	1580	800	96	52
190–209	450	185	1600	99	650	800	138	150	1300	295	800	464	640	1700	900	102	58
210–229	460	190	1700	98	680	850	140	147	1300	320	820	470	640	1680	920	108	57
230–249	470	188	1700	94	680	860	130	140	1300	340	840	470	640	1600	900	104	56
250–269	470	185	1680	86	660	850	120	130	1280	340	830	467	635	1500	860	101	52
^{137}Cs	464	170	1632	68	674	816	88	106	1240	332	795	460	603	1480	843	101	34
^{60}Co	448	168	1573	49	630	795	60	84	1197	295	788	445	570	1480	805	100	18

$$d_{jk} = I.m_k.P_{jk}.(\frac{FSD}{FMD})^2.S.(\frac{FMD}{FSD})^2.t = I.m_k.P_{jk}.S.t$$

where

- d: bone marrow dose of individual
- I: air dose on surface or tumor
- P: percent depth dose in the infinite FSD
- m: bone marrow weight in unit area
- FSD: focus skin distance or focus tumor distance
- FMD: focus marrow distance
- S: irradiation area at surface or tumor
- t: number of irradiation.

"I", "d" and "t" were obtained from survey cards and "m" from Table 5. The only factor to be determined by this subgroup was "p" in each representative quality of radiation. The actual dosimetry performed in four standard mannuquin phantoms. Each of the phantoms was constructed to represent the standarized stature of the Japanese of age between 0 and 2, 3 and 7, 8 and 14, and over 15 years. The phantoms consisted of M3 (Paraffin, MgO, Ca_2Co_3) for solft tissue, cork for lungs and A1 (Paraffin, Ca_3PO_4, animal charcoal) for bone.

Table 7 gives the results of the dosimetry and it was performed in several points in the phantoms and the other position was calculated by the graphical correction method.

Calculation and Summary

As formerly mentioned, the contribution of bone marrow dose is mainly on fixed field irradiation, irradiation techniques other than the fixed field were excepted from calculation because they were comparatively small in number and accumpanied by complexity in evaluation. The cards of Betatron and Lineac were also excepted from the same reasons.

The incomplete or unreliable cards, as shown in Table 8 were also excluded. Such dicarded cards were approximately 10 percent of all survey cards.

The results of bone marrow dose calculated from the survey cards is 83.8×10^7 gram-rads. The total

Table 8. Number of answered card calculated and results

No. of answered cards	18,786
No. of fixed field	17,369
No. of cards excepted by consistency check*	906
No. of cards calculated	16,463

*containing 55 cards of high energy apparatus just as lineac or betatron.

$$D = 83.8 \times 10^8 . \frac{100}{64.7} . \frac{18786}{16843} . \frac{12}{1} . \frac{1}{10^8} = 172 \text{ (g-rads)}$$

$$D_s = 30.2 \times 10^8 . \ \text{〃} \ . \ \text{〃} \ . \ \text{〃} \ . \ \text{〃} = 62 \text{ (g-rads)}$$

$$172 . \frac{1}{781.6} = 220 \text{ (mrem)}$$

$$62 . \ \text{〃} \ = 79.4 \text{ (mrem)}$$

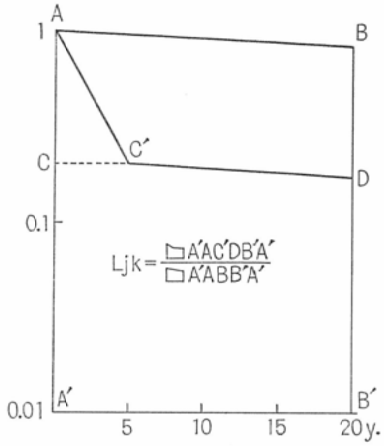


Fig. 5. Estimation of L_{jk}

Table 9. Life expectancy factor in each age group and patient for 20 years

(male)

Disease	0–139, 210–229, 240–999	140, 141, 178, 191, 194	170, 171, 172, 179, 192	143, 144, 161, 173, 174, 175 177, 193	142, 145, 146, 148, 160, 176, 180, 181, 195, 197, 200, 201, 205, 230–239	147, 151, 154, 196, 202	150, 162, 198, 199	152, 153, 155, 156, 157, 158, 159, 163, 164, 165, 190, 203, 204
Age \ 5 years survival rate	normal	60%	40%	30%	20%	10%	5%	1%
0–10	0.99	0.64	0.46	0.37	0.28	0.17	0.12	0.05
11–15	0.99	0.64	0.46	0.37	0.28	0.17	0.12	0.05
16–21	0.98	0.64	0.46	0.37	0.28	0.17	0.12	0.05
22–24	0.98	0.64	0.46	0.37	0.28	0.17	0.12	0.05
25–26	0.97	0.64	0.46	0.37	0.28	0.17	0.12	0.05
27–32	0.97	0.64	0.45	0.37	0.28	0.17	0.12	0.05
33–35	0.96	0.63	0.45	0.36	0.28	0.17	0.12	0.05
36–40	0.94	0.63	0.45	0.36	0.27	0.17	0.12	0.05
41–43	0.92	0.62	0.45	0.36	0.27	0.17	0.12	0.05
44	0.91	0.61	0.44	0.36	0.27	0.17	0.11	0.05
45	0.90	0.61	0.44	0.36	0.27	0.17	0.11	0.05
46	0.89	0.61	0.44	0.35	0.26	0.17	0.11	0.05
47	0.88	0.60	0.43	0.35	0.26	0.16	0.11	0.05
48	0.87	0.60	0.43	0.35	0.26	0.16	0.11	0.05
49	0.85	0.59	0.43	0.35	0.26	0.16	0.11	0.05
50	0.84	0.59	0.43	0.34	0.26	0.16	0.11	0.05
51	0.82	0.58	0.42	0.34	0.26	0.16	0.11	0.05
52	0.81	0.58	0.42	0.34	0.26	0.16	0.11	0.05
53	0.79	0.57	0.42	0.33	0.26	0.16	0.11	0.05
54	0.78	0.57	0.41	0.33	0.25	0.16	0.11	0.05
55	0.76	0.56	0.41	0.33	0.25	0.16	0.11	0.05

56	0.74	0.56	0.40	0.32	0.25	0.15	0.11	0.05
57	0.72	0.55	0.39	0.32	0.24	0.15	0.11	0.05
58	0.70	0.54	0.39	0.31	0.24	0.15	0.11	0.05
59	0.67	0.53	0.38	0.31	0.24	0.15	0.11	0.05
60	0.64	0.52	0.37	0.30	0.23	0.15	0.11	0.05
61	0.63	0.51	0.36	0.30	0.23	0.14	0.10	0.05
62	0.60	0.49	0.35	0.29	0.22	0.14	0.10	0.05
63	0.58	0.47	0.34	0.28	0.22	0.14	0.10	0.05
64	0.55	0.45	0.33	0.28	0.21	0.14	0.10	0.05
65-	0.40	0.38	0.33	0.27	0.21	0.13	0.10	0.05

(female)

Disease	0–139, 210–229, 240–999	140, 141, 178, 191, 194	170, 171, 172, 179, 192	143, 144, 161, 173, 174, 175, 177, 193	142, 145, 146, 148, 160, 176, 180, 181, 195, 197, 200, 201, 205, 230–239	147, 151, 154, 196, 202	150, 162, 198, 199	152, 153, 155, 156, 157, 158, 159, 163, 164, 165, 190, 203, 204
Age \ 5 years survival rate	Normal	60%	40%	30%	20%	10%	5%	1%
0–10	0.99	0.64	0.46	0.37	0.27	0.17	0.12	0.05
11–15	0.99	0.64	0.46	0.37	0.27	0.17	0.12	0.05
16–21	0.99	0.64	0.46	0.37	0.27	0.17	0.12	0.05
22–24	0.98	0.64	0.46	0.37	0.27	0.17	0.12	0.05
25–26	0.98	0.64	0.46	0.37	0.27	0.17	0.12	0.05
27–32	0.98	0.64	0.46	0.37	0.27	0.17	0.12	0.05
33–35	0.97	0.64	0.46	0.37	0.27	0.17	0.12	0.05
36–40	0.96	0.63	0.45	0.36	0.27	0.17	0.12	0.05
41–43	0.95	0.63	0.45	0.36	0.27	0.17	0.12	0.05
44	0.94	0.63	0.45	0.36	0.27	0.17	0.12	0.05
45	0.93	0.62	0.45	0.36	0.27	0.17	0.12	0.05
46	0.93	0.62	0.44	0.36	0.27	0.17	0.12	0.05
47	0.92	0.61	0.44	0.35	0.26	0.16	0.11	0.05
48	0.92	0.61	0.44	0.35	0.26	0.16	0.11	0.05
49	0.91	0.60	0.44	0.35	0.26	0.16	0.11	0.05
50	0.90	0.59	0.44	0.35	0.26	0.16	0.11	0.05
51	0.89	0.59	0.43	0.35	0.26	0.16	0.11	0.05
52	0.88	0.58	0.43	0.34	0.26	0.16	0.11	0.05
53	0.87	0.58	0.43	0.34	0.25	0.16	0.11	0.05
54	0.86	0.57	0.42	0.34	0.25	0.16	0.11	0.05
55	0.84	0.57	0.42	0.33	0.25	0.16	0.11	0.05
56	0.83	0.56	0.41	0.33	0.25	0.16	0.11	0.05
57	0.81	0.56	0.41	0.33	0.25	0.16	0.11	0.05
58	0.79	0.55	0.40	0.32	0.24	0.16	0.11	0.05
59	0.77	0.55	0.39	0.32	0.24	0.16	0.11	0.05
60	0.75	0.54	0.39	0.32	0.24	0.16	0.11	0.05
61	0.73	0.53	0.38	0.31	0.23	0.15	0.10	0.05
62	0.70	0.51	0.37	0.31	0.23	0.15	0.10	0.05
63	0.68	0.50	0.36	0.30	0.23	0.15	0.10	0.05
64	0.65	0.48	0.35	0.30	0.23	0.15	0.10	0.05
65-	0.50	0.40	0.30	0.26	0.20	0.13	0.09	0.05

Table 10 a. Bone marrow and bone marrow significant dose (age dependency) %

Age	Bone marrow dose		Bone marrow signifianta dose	
	male	female	male	female
0– 4	0.1	0.1	0.1	0.1
5– 9	0.0	0.1	0.1	0.1
10–14	0.3	0.2	0.2	0.1
15–19	0.2	0.2	0.2	0.3
20–24	0.7	0.6	0.7	0.7
25–29	0.5	1.3	0.7	1.6
30–34	1.2	4.3	1.1	5.5
35–39	1.1	7.2	0.8	9.0
40–44	1.1	8.1	0.7	10.5
45–49	1.6	9.7	1.1	11.7
50–54	3.2	13.7	1.9	16.6
55–59	4.0	10.8	2.1	11.9
60–64	4.7	9.5	2.6	9.5
65–	5.7	9.6	2.6	7.6
total	24.5	75.4	14.8	85.2

Table 10 b. Bone marrow and bone marrow significant dose (apparatus dependency) %

Bone marrow dose

age		superficial X-ray	deep X-ray	radio-isotopes	acceralator	total
0– 2	m	0.00	0.05	0.01	—	0.06
	f	0.00	0.03	0.03	—	0.06
3– 7	m	0.00	0.02	0.01	—	0.03
	f	0.01	0.01	0.04	—	0.06
8–14	m	0.02	0.18	0.13	—	0.33
	f	0.01	0.09	0.11	—	0.21
15–	m	0.10	5.91	15.66	0.12	22.12
	f	0.21	31.15	45.74	0.10	77.10
total	m	0.12	6.15	15.81	0.12	22.54
	f	0.23	31.28	45.92	0.10	77.43

Bone marrow significant dose %

age		superficial X-ray	deep X-ray	radio-isotopes	acceralator	total
0– 2	m	0.00	0.06	0.01	—	0.06
	f	0.00	0.02	0.02	—	0.05
3– 7	m	0.01	0.01	0.01	—	0.03
	f	0.01	0.02	0.04	—	0.07
8–14	m	0.06	0.11	0.77	—	0.94
	f	0.02	0.21	0.06	—	0.28
15–	m	0.27	3.79	8.57	0.06	12.69
	f	0.21	38.56	47.76	0.06	86.59
total	m	0.34	3.97	9.35	0.06	13.01
	f	0.25	38.81	47.88	0.06	87.00

Table 11. The correction factor on P-values under age of 14

Energy	age	A	B	C
100 kV	0– 2	0.24	0.40	0.32
	3– 7	0.44	0.68	0.56
	8–14	0.75	0.86	0.80
150 kV	0– 2	0.23	0.33	0.28
	3– 7	0.43	0.58	0.50
	8–14	0.75	0.81	0.78
200 kV	0– 2	0.22	0.30	0.26
	3– 7	0.42	0.50	0.46
	8–14	0.74	0.77	0.75
Co-60	0– 2	0.20	0.26	0.23
	3– 7	0.40	0.48	0.44
	8–14	0.73	0.75	0.74

Position	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
1	C	C	C	C	C	C	C	C	C	C	C	C	C	A	C	C
2	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
3	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
4	B	C	C	C	B	B	B	B	B	B	B	B	C	C	C	B
5	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
6	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
7	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
8	—															
9	—															

The calibration factor is received from position (right table), age and energy (left table). The number of the positioning is shown on the Figure 1.

results are shown in Table 8. After making a correction in regards with recovery factor and card selecting factor and extention from one month to one year, the bone marrow dose per quanta is 172 gram-rad as shown in Table 8. Life span factor explained in Fig. 5 was also punched into the IBM cards from the tables. Life span factor can be calculated from Figure 5 which show the mortality curve of normal parson and patient. Mortality carves of the patient is constructed from Table 9 which shows the survival rate at five years after irradiation.

Because the leukemia significant radiation is considered to be induced with 20 year, the life significant factor is the ratio of integral mortality till 20 years between the patient and normal person.

The significant bone marrow dose corrected by lifespan factor was 62 gram-rads per person-year as shown in Table 8. Bone marrow dose and significant bone marrow dose by fixed field irradiation calculated from the selected answered cards as a function of age group shown in Table 10. On this results, the distribution of active bone marrow in the lower age group is considered as same as the distribution of adult and it is corrected only by body length and weight in each group.

Bone marrow volume dose and significant bone marrow volume dose devided by the weight of bone marrow yield 220 and 70 mrem respectively which is to be compared with 120 mrem received from natural radiation which is accepted by UN report in 1964.

The results are shown in following.

$$D = S.12/1.r.\frac{16000}{13000}.1/10^8$$

$$Ds = \quad〃 \quad\quad 〃$$

where

S: summarized data from IBM cards

12/1: correction from month to year

r: correction by recovery

16000/13000: correction by consistency check

10^8: total population of Japan.

Errors

The error in "N" is negligibly small in comparison with thr error in "d". The error in "d" consists of two parts,one is attributed to the study on the distribution of bone marrow and the other to the unreliability of the doses reported from many of the facilities under investigation. Though the unreliability of radiotherapy apparatuses at many of facilities is supposed to play and important role in the error, no accurate information as to the part of the error attributed to the unreliability of the apparatuses has been reported so far. We can, however, reasonably assume that the part of the error may be at the same level as or less than the part of error due to the study on the distribution of bone marrow. Since the latter is less than 34 percent, the error in "d" is estimated as below 70 percent.

Addendum

In the consequence of the nation-wide survey on radiotherapeutic apparatuses (teleradiotherapy apparatuses), some informations which are not directly related to the present investigation but valuable in Radiology are obtained. These informations are added briefly in this report.

Acknowledgement

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