Preliminary Mortality Survey from 1973 to 1977 of Japanese Radiological Technologists and Analyses of the Association of Mortality with Cumulative Doses

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我国診療放射線技師の死亡調査(1973—77年)ならびに蓄積線量と死亡率の関連

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我国の診療放射線技師は96.4%が日本放射線技師会に所属し，1980年3月末現在の会員数は14,020人，98.1%が男子（1977年調査）である．彼らは低線量反覆被曝を受け，あるいは受けた可能性があるので，ヒトの放射線影響を調査研究する上で非常に貴重な集団と考えられる．

日本放射線技師会は，会に所属している放射線技師の死亡調査を行い，1941年から1978年の間に395名の死亡者があったことを確認した．そこで，このデータを用いて，粟冠は1955年から1965年の期間，北畠らは1966年から1972年の期間の死亡分析を行った．著者らは，さらに，1973年から1977年の期間の死亡者について同様の分析を加えた．その結果，著者らは，粟冠，北畠らと同様，人口動態統計，疾患別年齢別死亡率（1976年発表）を用いて算出した期待死亡の総数が観測死亡の総数より大きいこと，悪性腫瘍による死亡についても期待数が観測数より大きいことを見出した．ただ，皮膚癌については，観測数が期待数より有意に大きく，これも北畠らの観察結果と一致した．

ついで，著者らは395名の死亡者中268名について蓄積線量を推定した．そして，がんによる死亡者の平均蓄積線量と非がん疾患による死亡者のそれを比較したが，有意差は認めなかった．また，主要部位のがんによる死亡率と蓄積線量の関連も分析したが，これも有意な結果はえられなかった．

Introduction

It is now clear that the most important late somatic effect of low doses of radiation is the induction of malignant diseases, as evidenced by the increased incidences in exposed populations. Thus, several surveys have continued for prolonged periods of time with regard to the frequency of cancer among irradiated persons[1)2)]. Extended studies in occupationally exposed workers would be informative and pertinent, if exposures to be both external and internal radiation were adequately known, if an appropriate control population was studied, and if the numbers observed and the time of observation were sufficient[2)].

In Japan, Sakka[3)], Kitabatake and colleagues[4)] studied mortality and cause of death among Japanese radiological technologists. Sakka's studies ranged from 1955 to 1965. Kitabatake et al. reported the results from a survey extending from 1966 to 1972. We studied the mortality and cause of death in Japanese radiological technologists from 1973 to 1977, as a part of a study of the members of the Japan Association of Radiologic Technologists. We also estimated cumulative doses from occupational exposure for the majority of deaths. The mean dose of radiation in the case of deaths due to cancer was then calculated and proportional mortalities for cancers were observed in relation to the estimated dose level. We herein report the results from our survey on the mortality and cause of death and results from tests regarding the association of mortality with levels of radiation exposure among radiological technologists in Japan.

Sample for the Study and Methods

The Japan Association of Radiologic Technologists was founded in 1946 and authorized in 1951. At the end of March, 1980, there was a total number of 14,020. About 96.4% of the radiological technologists in Japan belong to this association. The radiological technologists were all men in Japan before 1960, and still in 1977 98.1% of all technologists are men. Increment in the number of the technologists has been remarkable.

The Association surveyed the deceased radiological technologists in 1964, 1968 and 1978. The data collected, included name, sex, date of birth, length of service, date and cause of death. For this purpose, questionnaires were mailed to families and colleagues of the deceased. Cause of death was finally ascertained by inspection of the death certificate obtained at public offices. Data on 395 technologists who died from 1941 to 1978 were collected. However, all these data were not always available for analyses due to an incompleteness, mainly of dose information and cause of death. The numbers indicated as person-years and age distribution for the 5 years from 1973 to 1977 are shown in Table 1. Age distribution of the members is estimated as based on the data of the questionnaire sent out in 1977. The expected number of deaths from major causes was calculated as based on mortality recorded in the Vital Statistics of 1976. In the calculation of the expected deaths, correction was made for age.

Table 1. Age distribution of members of the Japan association of radiologic technologists from 1973 to 1977

Age class	% Distribution	Estimated No. 1973—1977	Age class	% Distribution	Estimated No. 1973—1977
20—24	6.54	3,988	50—54	9.00	5,488
25—29	22.74	13,867	55—59	6.32	3,854
30—34	13.36	8,147	60—64	4.00	2,456
35—39	13.49	8,227	65—	1.64	983
40—44	11.47	6,995			
45—49	11.44	6,976			
	Total			100.00	60,981*

*: Person-years

Estimation of the doses was carried out with two different methods, because the doses the technologists had been exposed to were not measured using a filmbadge in Japan before 1960. The first method was developed by Kitabatake and Okajima[5], who considered that the dose of exposure must be influenced by the following six factors: the attention to X-ray protection, the sensitivity of the X-ray film used, the intensity of intensifying screens, the shield of the control board, the shield of the X-ray tube and the quantity of X-ray work. On the historical consideration of such factors, a dose rate (R/Year) and the cumulative dose were calculated. The second method was developed by Yamamoto, one of the present authors[6]. The principle of the method is as follows: the radiographic density has been expressed as a Bits value[7], easily obtained from the values of technical factors for radiological exposure using a coversion table for both the present and past. On the other hand, the actual dose of radiation of a patient receiving an X-ray examination is now measureable and the relationship between the Bits value and the actual dose received can be determined. Therefore, the patient dose, especially the surface dose received during X-ray examination in the past, was obtained based on the relationship between the Bits and the dose. Thus, the dose the radiological technologists received from scattered radiation is calculated from the surface dose of the patient, taking into consideration the working conditions, particularly with regard to radiation protection. The dose of the

268 deceased radiological technologists were firstly estimated by the method of Kitabatake and Okajima. Secondly, the doses were calculated by the method of Yamamoto et al. from the doses obtained by the method of Kitabatake and Okajima using conversion factors, that is, the ratio of the mean dose estimated by Yamamoto's method to that by Kitabatake and Okajima's, in the Kanagawa sample; 38 members of the Kanagawa Branch of the Association who were considered to have received relatively high cumulative doses, before the end of the World War II.

The relationship of mortality to the dose of radiation exposure in the deceased radiological technologists was analyzed by the method developed by Hutchison et al.[8]. A brief account of the method will be given here. Mean cumulative doses were calculated by cause of death, using the data adjusted for age at death and the first year of employment. Significance of differences between mean cumulative doses was tested using the t-test, because the doses would have a suitably regular distribution. The dose distribution regarding cause of death as adjusted by age at death and the first year of employment was investigated using contingency table analysis. The significance of the relation between proportional mortality ratio, a ratio of observed to expected number of deaths and dose was investigated by use of trend statistic, using the mean cumulative dose in interval(<50, 50–99, 100–999, over 1,000R) as the independent variable.

Results

The number of expected deaths from 1973 to 1977, caluculated using the mortalities of the 1976 Japanese Vital Statistics is shown in Table 2.

A comparison between expected deaths and those observed in the case of major causes of death is shown in Table 3. The total number of deaths was 145 including 53 cases of malignant tumors. The total members of radiological technologists from 1973 to 1977 was estimated to be 60,981 person-years as shown in Table 1 and the total expected number of deaths and that from malignant tumors to 273.0 and 67.7, respectively. There were three cases of skin cancers and the difference between the observed and expected numbers was statistically significant at 1%. The number of observed deaths and those who died from malignant tumors were markedly less than expected. For brain tumor, there was 1 observed vs. 0.1 expected deaths. The difference was at a significant level of 5%. On the contrary, 21 were observed vs. the expected 52.1 for cerebral vascular disease. The difference was statistically significant at 1% level. Leukemia and aplastic anemia were not recorded in this investigation.

The number of deaths, mean cumulative doses and standard deviations, obtained from the data adjusted for age at death and the first year of employment are shown by cause of death, in Table 4. Mean cumulative doses for all cancer deaths, deaths from oesophageal cancer, from rectal cancer and deaths from leukemia proved to be higher than in cases of non-cancer deaths. However, the differences between the doses and those related to the non-cancer deaths were not statistically significant. On the other hand, mean cumulative dose for stomach and lung cancer was lower than that of non-cancer deaths and difference in mean cumulative dose between lung cancer and non-cancer deaths was statistically significant. The doses in this table were computed by the dose obtained by the method of Yamamoto et al.. When the doses were estimated by Kitabatake and Okajima's method, the mean

Table 2. Expected number of deaths among radiological technologists

Age class	Malignant tumor								
	Skin	Leuk-emia	Esoph-agus	Stomach	Lung	Malig. lymphoma	Brain tumor	Others	Total
20–24	0.0012	0.0877	0.0	0.0359	0.0080	0.0379	0.0020	0.1085	0.2812
25–29	0.0028	0.3189	0.0	0.3882	0.0555	0.1262	0.0180	0.6199	1.5295
30–34	0.0057	0.6681	0.0081	0.5458	0.0733	0.1018	0.0073	0.1369	1.5470
35–39	0.0074	0.7075	0.0411	1.0777	0.1728	0.1234	0.0271	0.7495	2.9065
40–44	0.0091	0.6156	0.0909	1.6648	0.3218	0.1567	0.0287	1.4081	4.2957
45–49	0.0363	0.3348	0.3139	3.1811	0.7883	0.2316	0.0153	3.1984	8.0997
50–54	0.0406	0.3238	0.4994	4.0062	1.1086	0.2651	0.0230	4.3317	10.5984
55–59	0.0590	0.3045	0.6937	5.0950	1.8301	0.2921	0.0092	5.1409	13.4245
60–64	0.0437	0.2358	0.7515	5.2608	1.9918	0.2495	0.0098	5.1173	13.6602
65–	0.0284	0.1219	0.6124	4.4510	1.8804	0.1214	0.0042	4.1154	11.3351
Total	0.2342	3.7186	3.0110	25.7065	8.2306	1.7057	0.1446	24.9266	67.6778

Age class	Aplast. anemia	Heart dis.	Cereb. vas.	Peptic ulcer	Tuber-culosis	Acci-dent	Others	Total
20–24	0.0156	0.2313	0.0638	0.0160	0.0120	1.5673	1.8488	4.0360
25–29	0.0582	1.1232	0.4160	0.0693	0.0971	3.8550	6.4135	13.5618
30–34	0.0367	1.0265	0.6843	0.0815	0.1304	2.2567	4.4206	10.1837
35–39	0.0732	1.6536	1.5631	0.1563	0.2633	2.4928	5.9547	15.0635
40–44	0.0252	2.2874	3.2877	0.2588	0.4547	2.8959	10.3512	23.8566
45–49	0.0419	3.5647	5.4343	0.3767	0.7813	3.2299	10.3231	31.8516
50–54	0.0406	4.0501	6.3606	0.3842	0.9769	2.7989	9.5623	34.7720
55–59	0.0840	4.9370	8.0433	0.4047	1.0483	2.4511	9.6612	40.0541
60–64	0.0793	5.4990	9.3426	0.4593	1.0143	1.7634	9.4749	41.2930
65–	0.0419	9.4103	16.8968	0.6596	0.9977	1.2002	17.7393	58.2809
Total	0.4966	33.7831	52.0925	2.8664	5.7760	24.5112	85.7496	272.9532

Table 3. Comparison of the expected and observed numbers of deaths among Japanese radiological technologists, 1973—1977

Cause of death	Expected	Observed	Test
Malignant tumors	67.6778	53	ns
Skin cancer	0.2342	3	$p<0.01$
Leukemia	3.7186	0	ns
Esophageal ca.	3.0110	3	ns
Stomach ca.	25.7065	15	ns
Lung ca.	8.2306	10	ns
Malignant lymphoma	1.7057	2	ns
Brain tumors	0.1446	1	$0.05>p>0.01$
Others	24.9266	19	
Aplastic anemia	0.4966	0	ns
Tuberculosis	5.7760	3	ns
Heart diseases	33.7831	29	ns
Cerebral vascular dis.	52.0925	21	$p<0.01$
Peptic ulcer	2.8664	2	ns
Accidents	24.5112	17	ns
Others	85.7496	20	
Total	272.9532	145	

cumulative dose for leukemia was 3,686R which proved to be higher than that of 1,236R for non-cancer deaths, and the difference here is statistically significant.

Table 4. Mean cumulative dose of radiation for non-cancer deaths and cancer deaths by site —adjusted for age at death and the first year of employment—

Statistics	Non-cancer	All cancer	Esophagus	Stomach	Rectum	Lung	Leukemia
No. of cases	176	90	6	24	8	13	7
Mean (R)	568	670	610	463	730	210	696
S.D.	93	103	93	53	48	37	41
T-test (P-value)		0.23	0.38	0.16	0.063	0.0003	0.11

The dose distribution regarding cause of death as adjusted by age at death and the first year of employment was investigated, using contingency table analysis. The observed number of deaths and the number expected, for cancer of all sites, in four dose categories, are shown in Table 5. The significance of the relation between proportional mortality ratio and dose was investigated by use of a trend statistic, using the mean cumulative dose in interval as the independent variable. Although the observed numbers in two dose categories, 50 to 99 and over 1,000R, are larger than those for the expected, p-values for the trend test show that the relationship is not statistically significant.

Relative risks of mortality ratio for a site of cancer by dose are shown in Table 6. For all the cancers and some specific sites of cancer, particularly lung cancer, in some dose categories, values of relative risk exceed 1.00. However, the statistical tests for trend do not show significant associations for any site of cancer.

Table 5. Relative risk of mortality ratio for cancer of all sites, by dose. —adjusted for age at death and the first year of employment—

	Dose (R)					Statistical test	
	Total	<50	50–99	100–999	1000+	Linear trend	Homogeneity
Observed deaths	90	23	22	27	18	p=0.43	p=0.57
Expected		24.54	19.07	29.90	16.49		
Relative risk		1.00	1.23	0.96	1.16		
Total deaths	268	87	52	84	45		

Table 6. Relative risk of mortality ratio for specific site of cancer, by dose. —adjusted for age at death and the first year of employment—

Site	Total	Dose (R)				Statistical test	
		<50	50–99	100–999	1000+	Linear trend	Homogeneity
All cancers	(90)	1.00	1.23	0.96	1.16	p=0.43	p=0.57
Esophagus	(6)	—	1.00	0.52	0.68	0.24	0.70
Stomach	(24)	1.00	1.33	0.79	0.81	0.039	0.21
Rectum	(8)	1.00	1.22	0.97	1.79	0.21	0.85
Lung	(13)	1.00	1.74	1.80	1.41	0.29	0.78
Leukemia	(7)	1.00	0.00	1.18	0.67	0.45	0.78

( ): No. of cases

Discussion

The Japan Association of Radiologic Technologists reported that, from 1941 to 1978, 395 deaths occurred among Japanese radiological technologists who belong to the Association. Using these data, Sakka, Kitabatake et al., and the present authors studied mortality and cause of death among these technologists.

Sakka[3] analyzed the mortality among Japanese radiological technologists for the years from 1955 to 1965 and found total of 91 deaths including 28 cases of malignant tumors. He estimated the total number of radiological technologists from 1955 to 1965, to be 74,721 person-years and the total expected number of deaths and deaths from malignant tumors to 324.6 and 47.5, respectively, based on the Japanese male mortality rates for this period. The number of observed deaths and who died from malignant tumors did not exceed the expected number.

Kitabatake et al.[4] also analyzed the mortality and cause of death in Japanese radiological technologists from 1966 to 1972. The expected numbers of deaths from major causes were calculated based on mortalies taken from the Japanese Vital Statistics of 1970. Correction was made for age. Their study revealed that the total number observed was 134 and the expected number 292. These figures suggest that the much lower number of observed deaths as compared with expected deaths was attributable to the lack of the number of deaths reported. However, there were 6 observed vs. 0.22 expected deaths for skin cancer. In the case of aplastic anemia, 2 were observed vs. the expected 0.48. It was claimed that radiation might have induced skin cancers and aplastic anemia among radiological technologists because the difference between the observed and the expected deaths from skin cancer was at a statistically significant level of 1%, and for aplastic anemia the difference was at a significant level of 5%. For leukemia, there was no significant difference between the number of observed and expected deaths.

It can be mentioned, therefore, that the observed numbers of deaths in the three studies were less than the expected numbers. In other words, the observed numbers were about a half of the expected, in any study. Kitabatake attempted to interpret the data in the incomplete answers on the questionnaires. We assumed, however, there are other possibilities such as the bias introduced by the healthy worker effect due to their professional situations. It may also be that follow-up of the seceding members was incomplete.

Although the observed numbers were less than the expected, Kitabatake et al. and the present authors found that deaths from skin cancer were significantly more frequent than the expected. This is attributed to the idea that radiological technologists are probably more exposed to scattered radiation. Takahashi has reported data suggesting a relatively high risk of radiation-induced skin cancer among the Japanese[9], although no increase in skin cancer has been reported among the atomic bomb survivors[10]. Walinder[11] pointed out, however, that their procedures without stringent radiation protection in the earlier periods would possibly induce skin cancer.

Miller and Jablon reported that in a 18-year follow-up study (1946 to 1963), there was no significant excess occurrence of cancer among 6,560 men who served in the Army during World War II as radiological technologists, as compared with 6,826 controls[12]. Extension of the follow-up by 11 years (1964 to 1974) also indicated that no statistically significant differences were found between these two groups for individual sites of cancer or for deaths from other causes[13]. Failure to observe significant increases in mortalites may well reflect the shorter duration of radiation exposure and lower cumulative doses received by technologists and two- or three-fold increase in risk could by chance have gone undetected in a survey of this size[1].

We estimated the cumulative doses of radiation exposure for the majority of deaths and the mean dose for cancer deaths was compared with that for non-cancer deaths. Also the proportional mortality ratios for cancers were observed in relation to the estimated dose level. However, statistical tests regarding the relationship of mortality to the dose of radiation exposure revealed no correlation for the majority of death by cancer, when we used the data adjusted by age at death and the first year of employment.

Mean cumulative doses estimated were considerably high for either non-cancer death or cancer death, as shown in Table 4 (estimated by the method of Yamamoto et al.). The mean cumulative doses estimated by Kitabatake and Okajima's method were much higher than those by the method of Yamamoto et al.. Particularly, the mean cumulative dose for leukemia proved to be higher than that for non-cancer deaths. However, clarification of the reason for these findings awaits results based on a much more adequate analysis, that is, a population-based study.

Mancuso et al.[14][15] reported their findings on the mortality experience of men at the Hanford plant, U.S.A., who were employed for various intervals between 1943 and 1971. The reports are largely limited to analysis of data on the deaths for which deaths certificates were available. Analysis of the at-risk experience of the survivors is not included. The principal method of analysis used in their reports is described as the comparative mean dose method. From this point of view, their reports have received a skeptical review by several investigators. Recently, Hutchison et al.[8] analyzed the reports of Mancuso et al. and proposed new improved analytic methods using data adjusted for age and calender year of death. Thus, we adopted their method to analyze the association of mortality with dose of radiation exposure in the deceased radiological technologists. Hutchison et al. concluded, however, that their analyses as well as that of Mancuso et al. were preliminary and did not take advantage of the available data on the total exposed population.

A cohort analysis should provide a better understanding of the mortality experience of radiological technologists. The Health Study Group on Japanese Radiological Technologists recently began recording, on tape, data of the members who secede. Analyzation of the population-based mortality of the Japanese radiological technologists is planned in the near future.

Conclusion

The Japan Association of Radiologic Technologists reported that, from 1941 to 1978, 395 deaths occurred among Japanese radiological technologists who belong to the association. Using these data, Sakka, Kitabatake and colleagues, and the present authors studied mortality and cause of death among these technologists for 11 years from 1955 to 1965, for 7 years from 1966 to 1972, and for 5 years from 1973 to 1977, respectively. In general, the number of cancer deaths in the three studies was less than expected. However, Kitabatake et al. and the present authors found that deaths from skin cancer were significantly more frequent than expected. The present authors recently estimated the cumulative doses of radiation exposure for the majority of deaths (268 out of 395). The mean dose of radiation related to cancer deaths was then compared with that for non-cancer deaths. Also the proportional mortality ratios for cancers were observed in relation to the estimated dose level. In the present study, however, statistical tests to assess for the relationship between mortality and dose of radiation exposure showed no correlation, for the majority of deaths from cancer.

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