Agreement between Death Certificate and Autopsy Diagnoses among Atomic Bomb Survivors

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Based on the Atomic Bomb Casualty Commission/Radiation Effects Research Foundation series of over 5,000 autopsies, we examined death certificate accuracy for 12 disease categories and assessed the effect of potential modifying factors on agreement and accuracy. The overall percentage agreement between death certificate and autopsy diagnoses was only 52.5%. Although neoplasms had the highest detection rate, almost 25% of cancers diagnosed at autopsy were nevertheless missed on death certificates. Confirmation and detection rates were above 70% for neoplasms and external causes of death only. Confirmation rates were between 50 and 70% for infectious diseases and heart and other vascular diseases. Detection rates reached a similar level for infectious, cerebrovascular, and digestive diseases. Specificity rates were above 90% for all except the cerebrovascular disease category.

Overall agreement decreased with increasing age at death and was worse for deaths occurring outside of hospital. There was some suggestion that agreement improved over time, but no indication that radiation dose, sex, city of residence, or inclusion in a biennial clinical examination program influenced agreement. Since the inaccuracy of death certificate diagnoses can have major implications for health research and planning, it is important to be aware that their accuracy is low and that it can vary widely depending on cause, age, and place of death. (Epidemiology 1994; 5:48-56)

Keywords: autopsy, death certificates, mortality, cause of death, validation study, sensitivity, specificity, radiation exposure, neoplasms, cardiovascular diseases, infectious diseases.

Recent evaluation of mortality data has revealed an apparent increase in mortality rates over time for several major cancer sites.[1,2] Findings from other studies, however, raise questions concerning the overall accuracy of death certificate diagnoses[3-12] and the possibility that observed increases in mortality may be due, in part, to improvements in death certificate diagnoses.[13-15]

When mortality data from the atomic bomb survivors indicated an increased risk for non-cancer causes associated with radiation,[16] the issue of misclassification in death certificate diagnoses was also raised. The Atomic Bomb Casualty Commission (ABCC) and later the Radiation Effects Research Foundation (RERF) have been conducting a study of the long-term effects of radiation exposure from the atomic bombs.[17,18] The Life Span Study (LSS) includes about 94,000 survivors (exposed and nonexposed) and 27,000 individuals who were not in Hiroshima or Nagasaki at the time of the bombings (not-in-city). Since the start of the ABCC/RERF research program, several analyses of the accuracy of death certificate diagnoses compared with autopsy findings have been published.[19-23] The earlier studies, however, either analyzed cancer only or were limited to data collected at the time of analysis. The present paper is based on all autopsies conducted on deceased members of the LSS cohort. It aims to evaluate the representativeness of the autopsy sample in relation to the entire LSS cohort, measure the accuracy of death certificate diagnoses for non-cancers as well as cancers, and assess the effect of potential modifying factors on agreement between death certificate and autopsy diagnoses.

Methods

During the 40 years of the ABCC/RERF autopsy program (1950-1987), procurement policies, techniques, and success rates changed. Before 1961, the autopsy program included cases regardless of whether they belonged to the LSS cohort. Of the 2,873 autopsies performed through 1960, only about one-quarter of the cases were part of the LSS cohort. After 1961, however, emphasis was placed on obtaining a repre-

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sentative sample of LSS deaths. To maintain consistency and to enable analyses related to radiation dose, we restricted this study to autopsies conducted on members of the LSS population. The "underlying cause" of death from death certificate and "principal cause" of death at autopsy were originally coded according to the *International Classification of Diseases* (ICD) edition used at the time of death. We analyzed the data using 12 major categories, or a refinement in which the neoplasms were studied in greater detail. The categories as classified in ICD9[24] are: infectious and parasitic (001-139; 511.9); neoplasms (140-208; 210-229; 230-239); endocrine and metabolic (240-279); blood (280-289); cerebrovascular (430-438); heart and other circulatory (390-429; 440-459); respiratory (460-510; 511.0, 511.1, 511.8; 512-519); digestive (520-579); urinary (580–599); ill-defined (780-799); all other diseases (290-389; 600-779), and external causes (800-999).

To assess the representativeness of the autopsy sample, the proportions of autopsies performed were compared by sex, age at death (<50, 50-59, 60-69, 70-79, >=80 years), year of death (1950-1960, 1961-1965, 1966-1970, 1971-1975, 1976-1987), place of death (hospital, other), death certificate diagnosis categories (as described above), radiation dose [not-in-city, <0.01, 0.01-0.49, 0.50-0.99, >=1 gray (Gy)], city of residence (Hiroshima, Nagasaki), and inclusion in the LSS Adult Health Study (AHS) biennial clinical examination program (yes, no). Logistic regression analyses, using the CATMOD procedure of the Statistical Analysis System (SAS) were performed to assess the main effects of covariates on the probability of agreement between death certificate and autopsy diagnoses. We excluded cases without dose estimates from these analyses. Selected interactions were also tested by adding the indicated terms to the main effects model and comparing to the reduced models.

The validity and completeness of the underlying cause of death coded on the death certificate were determined by calculating confirmation rate (positive predictive value), detection rate (sensitivity), and specificity using the principal cause of death on autopsy as the standard. In addition, we calculated the ratio of the detection to the confirmation rate. This ratio minus one, which we called *correction factor,* measures the extent to which a cause of death is over- or understated.

Results

Autopsies were performed on 6,613 (14.3%) of the 46,331 deaths occurring among members of the LSS cohort from 1950 to 1987. Of these, 5,130 (77.6%) were autopsied at RERF, and 1,483 (22.4%) were autopsied at hospitals outside RERF. The mean age at autopsy was 68 years, but it was somewhat less (63.7 years) for autopsies not performed at RERF. Compared with all deaths in the LSS cohort, proportionally more autopsies were performed on males, people who died in a hospital, and people who died of cancer (particularly leukemia) or non-neoplastic blood disorders than females, people who died outside of hospital, and persons who died of other diseases, respectively (Table 1). Individuals who died of external causes or who died after age 80 years were autopsied less frequently than those who died of disease or at younger ages. Before 1961, autopsy rates were low, but after the introduction of the LSS autopsy procurement program, the rates increased dramatically and then declined. Autopsies also were performed more frequently among decedents who had received higher radiation doses, had lived in Hiroshima, and who had belonged to the AHS study sample than those who had been exposed to lower radiation doses, lived in Nagasaki, or had not been included in the AHS sample. Because autopsies done at RERF were found to be more representative of the total LSS deaths than those done outside RERF, we restricted the rest of the data analysis to the 5,130 RERF autopsied cases.

When we assessed confirmation and detection rates, neoplasms, the single largest disease category, showed the best agreement (Table 2). Only 9.1% of deaths reported as due to cancers by the certificates were non-neoplastic disease as judged by autopsy. Nonetheless, 24.3% of cancers diagnosed at autopsy were missed on death certificate. In addition to neoplasms, confirmation and detection rates were above 70% solely for external causes of death. Confirmation rates were between 50 and 70% for two categories (infectious and parasitic diseases, and heart and other circulatory diseases), and detection rates reached a similar level of accuracy for infectious and parasitic, cerebrovascular, and digestive diseases. Specificity rates were above 90% for all except cerebrovascular diseases.

Using 12 cause-of-death categories, the overall percentage agreement between death certificate and autopsy diagnoses was 52.5% (Table 3). The kappa statistic was 0.44, which indicated moderate agreement according to the nomenclature suggested by Landis and Koch.[25] There was a meaningful difference in the level of agreement by the autopsy cause of death. We found that over one-third of the diseases erroneously reported as neoplasms on death certificates were actually digestive diseases according to autopsy findings.

TABLE 1. Autopsy Rates for Selected Factors by Place of Autopsy

	Place of Autopsy					
	RERF		Other		Total	
Factor	No.	Rate (%)	No.	Rate (%)	No.	Rate (%)
Sex						
Female	2,502	10.4	647	2.7	3,149	13.1
Male	2,628	11.8	836	3.7	3,464	15.5
Age at death (years)						
<50	501	9.5	237	4.5	738	14.0
50–59	527	10.2	238	4.6	765	14.8
60–69	1,267	13.4	427	4.5	1,694	17.9
70–79	1,743	11.8	471	3.2	2,214	15.0
≥80	1,092	9.3	110	0.9	1,202	10.3
Year of death						
1950–1960	652	5.6	75	0.7	727	6.3
1961–1965	1,810	29.4	281	4.6	2,091	33.9
1966–1970	1,467	22.7	281	6.6	1,895	29.3
1971–1975	791	12.2	292	4.5	1,083	16.6
1976–1987	410	2.6	407	2.6	817	5.2
Place of death						
Hospital	2,145	11.1	1,439	7.4	3,584	18.5
Other	2,985	11.2	44	0.2	3,029	11.4
Death certificate diagnosis						
Infectious	319	14.2	29	1.3	348	15.5
Neoplasms	1,240	12.2	871	8.5	2,111	20.7
Endocrine	119	11.4	32	3.1	151	14.4
Blood	32	14.6	29	13.2	61	27.9
Cerebrovascular	1,158	11.7	106	1.1	1,264	12.8
Heart, other circulatory	805	10.0	149	1.9	954	11.9
Respiratory	335	9.9	51	1.5	386	11.4
Digestive	391	11.5	134	3.9	525	15.4
Urinary	84	8.1	28	2.7	112	10.8
Ill-defined	327	10.5	7	0.2	334	10.7
Other diseases	166	13.2	23	1.8	189	15.0
External causes	154	6.2	24	1.0	178	7.1
Radiation dose (Gy)						
<0.01	1,496	9.0	393	2.4	1,889	11.4
0.01–0.499	1,908	13.0	523	3.6	2,431	16.6
0.50–0.990	230	14.5	72	4.5	302	19.0
≥1.0	221	19.1	84	7.2	305	20.8
Unknown dose	282	11.3	132	5.3	414	16.6
Not-in-city	993	10.4	279	2.9	1,272	13.3
City of residence						
Hiroshima	4,035	12.3	999	3.1	5,034	15.4
Nagasaki	1,095	8.1	484	3.6	1,579	11.6
AHS membership						
Yes	1,220	14.9	414	5.1	1,634	20.0
No	3,910	10.3	1,069	2.8	4,979	13.0

There was a great deal of overlap between cerebrovascular diseases and heart and other circulatory disease categories. Of the 697 misclassified cerebrovascular disease death certificates, 434 (62%) had an autopsy diagnosis of heart and other circulatory diseases. For the category of heart and other circulatory diseases, we observed less death certificate misclassification, and it was not concentrated in a single disease category. Almost half of the "ill-defined" causes of death were, in fact, circulatory diseases.

When we tested for main effects on the probability of agreement, we found that overall agreement de-

TABLE 2. Frequency and Confirmation, Detection, and Specificity Rates by Cause of Death among 5,130 LSS Deaths Autopsied at RERF

Disease Group	Number			Confirmation Rate (%)	Detection Rate (%)	Specificity (%)
	Autopsy	Death	Agreed			
Infectious	378	319	189	59.3	50.0	97.3
Neoplasms	1,489	1,240	1,127	90.9	75.7	96.9
Lip, etc	13	13	9	69.2	69.2	99.9
Digestive	854	725	629	86.8	73.7	97.8
Esophagus	50	42	29	69.1	58.0	99.7
Stomach	503	431	355	82.4	70.6	98.4
Colon	52	36	23	63.9	44.2	99.7
Rectum	42	44	29	65.9	69.1	99.7
Liver	60	96	33	34.4	55.0	98.8
Gallbladder	83	18	10	55.6	12.1	99.8
Pancreas	56	34	19	55.9	33.9	99.7
Other	8	24	1	4.2	12.5	99.6
Respiratory	228	153	124	81.0	54.4	99.4
Breast	37	29	28	96.6	75.7	100.0
Female genital	113	94	76	80.9	67.3	99.6
Male genital	25	8	4	50.0	16.0	99.9
Urinary	50	38	24	63.2	48.0	99.7
Hematopoietic	98	83	67	80.7	68.4	99.7
Other	449	416	213	51.2	47.4	95.7
Endocrine, nutritional, etc	60	119	25	21.0	41.7	98.1
Blood	16	32	7	21.9	43.8	99.5
Cerebrovascular	688	1,158	461	39.8	67.0	84.3
Heart, other circulatory	1,236	805	416	51.7	33.7	90.0
Respiratory	408	335	95	28.4	23.3	94.9
Digestive	358	391	184	47.1	51.4	95.7
Urinary	105	84	20	23.8	19.0	98.7
Ill-defined	46	327	9	2.8	19.6	93.8
Other diseases	191	166	52	31.3	27.2	97.7
External causes	155	154	109	70.8	70.3	99.1

TABLE 3. Agreement on Cause of Death from Death Certificate and Autopsy among Autopsies Performed at RERF

Cause of Death on Certificate	Cause of Death on Autopsy*												
	1	2	3	4	5	6	7	8	9	10	11	12	Total
1. Infectious	**189**†	48	0	0	9	22	24	13	3	0	9	2	319
2. Neoplasms	18	**1,127**	1	4	4	13	11	40	7	3	11	1	1,240
3. Endocrine	13	6	**25**	0	4	29	29	3	3	1	4	2	119
4. Blood	1	8	0	**7**	0	5	2	4	2	2	1	0	32
5. Cerebrovascular	20	71	3	1	**461**	434	62	37	17	7	27	18	1,158
6. Heart and other	46	61	14	1	89	**416**	82	27	23	10	30	6	805
7. Respiratory	25	33	4	0	45	76	**95**	17	8	4	20	8	335
8. Digestive	24	69	3	0	15	52	19	**184**	5	4	14	2	391
9. Urinary	9	18	2	0	10	19	2	0	**20**	1	3	0	84
10. Ill-defined	23	30	3	1	30	130	56	16	11	**9**	16	2	327
11. Other diseases	10	12	4	1	14	27	18	15	4	4	**52**	5	166
12. External causes	0	6	1	1	7	13	8	2	2	1	4	**109**	154
Total	378	1,489	60	16	688	1,236	408	358	105	46	191	155	5,130

* Percentage of agreement (2,694/5,130) × 100 = 52.5%; kappa = 0.44.
† The numbers in bold show agreement between the death certificate and autopsy.

creased with increasing age at death and was worse when people died outside of hospital. Analysis by time period suggested that agreement improved somewhat over time, but there was no indication that radiation dose, sex, city of residence, or inclusion in the AHS influenced agreement.

For the six disease categories with a sufficient number of cases, we looked for the effects of explanatory variables on confirmation and detection rates (Table 4). The one factor that influenced at least one of these two measures for every disease group was age at death. Confirmation and detection rates were poorer when persons died at ages 60 or older than when they died at younger ages. For neoplasms, detection rates were almost 35% lower for persons who died after age 75 compared with those who died before age 60. For persons dying from infectious diseases, the reduction in the detection rate was 79%.

Detection was notably better for deaths occurring in hospitals for infections, neoplasms, and digestive diseases. Confirmation was better for deaths in hospital for digestive diseases and worse for heart and other circulatory diseases. The effect of time period was not always consistent. For cerebrovascular diseases, there was a trend for detection rates to decrease and confirmation to increase over the years, whereas for heart and other circulatory diseases, the trends appeared to be in the opposite direction. Radiation dose appeared to have no modifying effect on agreement. For infectious diseases, there was some suggestion that decedents exposed to doses less than 0.01 Gy had higher confirmation rates than those with doses above 0.01 Gy. Given the large number of tests performed, however, this finding is of limited importance.

Although agreement and net change (the difference in the number of cases in a specific disease category, depending on whether the diagnosis from death certificate or autopsy is used) are frequently correlated, losses in one category can be compensated by additions from another category. Despite the fact that agreement was very poor for digestive diseases, the net change was relatively minor: on death certificate there were 391 and on autopsy 358 cases, for a net change of only 8%. For oral cancers, there was agreement on only 9 of a total of 17 oral cancers mentioned on either death certificate or autopsy. The mortality rate over the entire study period would be correct, however, because an equal number of oral cancers were reported on autopsy and on death certificate.

Specific diseases were often underreported, whereas the nonspecific rubric "ill-defined" was used too frequently (Table 5). The correction factor indicates that most of the more common forms of neoplasia would be understated in vital statistics. The death rate from heart and other circulatory diseases would be understated by about 35% based on death certificates. In contrast, the importance of endocrine diseases, diseases of the blood, and cerebrovascular diseases would be substantially overstated. The number of deaths in these categories is small, however, and the correction factors have wide confidence intervals.

When we analyzed neoplastic deaths in detail, we found that they often were confirmed to the specific organ system involved (Table 3). The detection rates, however, were smaller than the confirmation rates. Furthermore, when cancers were missed on death certificates, they were usually assigned to causes other than cancer, often to non-neoplastic diseases of the same organ system (Table 6). Eighty-seven per cent of the deaths reported as cancers of the digestive system on death certificates were confirmed at autopsy, but 26% of the digestive system neoplasms found on autopsy were missed on the death certificate. Of the missed cancers of digestive organs, 83% were recorded as non-neoplastic. Of these errors, 31% were assigned to non-neoplastic digestive diseases. Although it is common knowledge in Japan that the death rate from cancer of the stomach is among the highest in the world, still almost 30% of the deaths were incorrectly diagnosed on death certificates. Among decedents age 75 years or more, about one-half of the deaths were misclassified. For other organs within the digestive system, accuracy was especially poor for liver, gallbladder, and pancreatic cancer. Even when we combined these three organs into a single entity, the detection rate was only 50%.

Cancers of the respiratory system accounted for just over 4% of all deaths and 15% of deaths attributed to cancer on autopsy. The detection rate, however, was only 54% and was especially low for deaths occurring outside of hospital (44%) or among persons age 75 years or more (42.5%). Of the respiratory cancers reported as non-neoplastic, 38% were reported as tuberculosis. The confirmation and detection rates for leukemia were relatively high and, with the exception of year of death, did not vary meaningfully with any of the factors examined. After 1961, the confirmation rate improved, but the detection rate, unexpectedly, grew worse.

Discussion

The accuracy of death certification can be evaluated by comparison with the results of autopsy. The use of

TABLE 4. Adjusted Confirmation and Detection Rates by Explanatory Factors for Major Disease Groups

	Infectious		Neoplasms		Cerebrovascular		Circulatory		Respiratory		Digestive	
Factor	Confirmation	Detection	Confirmation	Detection	Confirmation	Detection	Confirmation	Detection	Confirmation	Detection	Confirmation	Detection
Age												
<60	0.63	0.53	0.94	0.86	0.61	0.76	0.51	0.59	0.31	0.46	0.71	0.51
60-74	0.41	0.32	0.91	0.80	0.39	0.66	0.48	0.39	0.32	0.31	0.44	0.49
≥75	0.20	0.11	0.88	0.56	0.33	0.62	0.47	0.38	0.23	0.20	0.44	0.43
P-value*	$P < 0.001$	$P < 0.001$	$P = 0.07$	$P < 0.001$	$P < 0.001$	$P = 0.12$	$P = 0.79$	$P < 0.001$	$P = 0.25$	$P = 0.01$	$P = 0.001$	$P = 0.57$
Place of autopsy												
Hospital	0.45	0.43	0.91	0.81	0.45	0.65	0.44	0.47	0.27	0.28	0.64	0.57
Other	0.35	0.18	0.92	0.70	0.43	0.72	0.53	0.44	0.30	0.35	0.43	0.39
P-value	$P = 0.11$	$P < 0.001$	$P = 0.42$	$P < 0.001$	$P = 0.69$	$P = 0.08$	$P = 0.01$	$P = 0.49$	$P = 0.53$	$P = 0.29$	$P < 0.001$	$P < 0.00$
Year												
<1961	0.45	0.38	0.87	0.70	0.19	0.71	0.60	0.35	0.22	0.18	0.51	0.42
1961-1965	0.45	0.41	0.93	0.79	0.28	0.76	0.56	0.31	0.39	0.29	0.60	0.56
1966-1970	0.47	0.38	0.93	0.77	0.56	0.72	0.46	0.47	0.28	0.26	0.554	0.52
1970-1975	0.38	0.22	0.91	0.76	0.63	0.56	0.36	0.56	0.26	0.35	0.41	0.49
1976-1987	0.26	0.14	0.91	0.75	0.61	0.65	0.44	0.60	0.29	0.53	0.59	0.39
P-value	$P = 0.81$	$P = 0.16$	$P = 0.27$	$P = 0.26$	$P < 0.001$	$P < 0.001$	$P < 0.01$	$P < 0.001$	$P = 0.37$	$P = 0.06$	$P = 0.29$	$P = 0.37$
Dose												
NIC†	0.39	0.36	0.91	0.76	0.40	0.60	0.47	0.35	0.31	0.32	0.58	0.61
<0.01 Gy	0.60	0.42	0.91	0.76	0.43	0.74	0.52	0.44	0.18	0.18	0.45	0.43
0.01-0.49	0.43	0.33	0.91	0.78	0.49	0.73	0.56	0.47	0.32	0.32	0.46	0.49
0.5-1.0	0.22	0.10	0.95	0.78	0.44	0.64	0.45	0.52	0.21	0.31	0.58	0.38
≥1.0	0.38	0.35	0.88	0.69	0.45	0.70	0.44	0.49	0.44	0.47	0.59	0.49
P-value	$P = 0.05$	$P = 0.14$	$P = 0.77$	$P = 0.47$	$P = 0.26$	$P = 0.08$	$P = 0.29$	$P = 0.06$	$P = 0.13$	$P = 0.08$	$P = 0.35$	$P = 0.25$

* Differences in rates between levels of a factor are adjusted for all other factors in the table.
† NIC, not-in-city.

TABLE 5. Estimated Adjustment Factors for Major Disease Categories

Disease Group	Correction Factor (%)
Infectious and parasitic	–15
Neoplasms	-17
Lip, etc	00
Digestive organs	–15
Esophagus	–16
Stomach	–14
Colon	-31
Rectum	+05
Liver	+60
Gallbladder	-78
Pancreas	–39
Other	-200
Respiratory	–33
Breast	–22
Genitourinary	–26
Hematopoietic	–15
Other	–07
Endocrine	+l00
Blood	+100
Cerebrovascular	+69
Heart, ocher circulatory	-35
Respiratory	–18
Digestive	+09
Urinary	-20
Ill-defined	+614
Other diseases	-13
External causes	–01

autopsy data as the "gold standard" for determining cause of death has certain limitations, however. Pathologists, of course, can err, and clinical data that are useful in determining the underlying cause of death are not always available to the pathologist. Furthermore, there may be selection factors biasing those deaths which come to autopsy. Unfortunately, many autopsy series are severely biased because the attending physician is more likely to request an autopsy when the cause of death is uncertain. In order to serve as the basis for an unbiased estimate of the accuracy of death certification, an autopsy series should satisfy several criteria: it should be unselected in terms of disease or patient characteristics; there should be no selection in relation to the skill of the attending physician; it should include deaths occurring outside of hospital; it should be representative of all deaths in the population to be studied; and the certifying physician must not be aware of the results of the autopsy.

The ABCC/RERF autopsy series has many of the desired characteristics. It includes more than 6,613 autopsies performed over a long period of time; persons of all ages and both sexes are represented; and death certificate diagnoses were determined independently of autopsy findings. One of the major strengths of the RERF autopsy series is that during most of the autopsy program, permission for autopsy was solicited from families of all deceased LSS subjects. Thus, unlike many other series, deaths selected for autopsy were not chosen for any clinical reason. Furthermore, in Japan, the very short time between death and cremation or burial provides no opportunity for the results of the autopsy to be made known to the doctor who certified the cause of death. In addition, it is one of the few series to include a large number of non-hospital deaths.

In this series, the rate of overall agreement was

TABLE 6. Cancer Deaths Erroneously Assigned to Other Causes of Death on Death Certificates

Cancers Missed	Number	Erroneous Certifications
Digestive organs	225	187 non-neoplastic (58 digestive; 62 vascular; 67 other) 38 other neoplastic (5 lung; 5 female genital; 21 ill-defined; 7 other)
Respiratory system	104	74 non-neoplastic (28 tuberculosis; 21 vascular; 10 respirator; 15 other) 30 other neoplastic (14 ill-defied; 16 other)
Genitourinary system	79	46 non-neoplastic (21 vascular; 5 digestive; 9 genitourinarv; 5 ill-defined; 6 other) 33 other neoplastic (17 digestive; 12 ill-defined; 4 other)
Hematopoietic	31	17 non-neoplastic (4 blood; 13 other) 14 other neoplastic (6 digestive; 6 ill-defined; 2 other)

52.5% when the underlying cause of death on death certificate and principal cause of death reported at autopsy for 12 disease categories were compared. Although it is difficult to compare with other studies because of different time periods, age composition, and place of death, some studies performed in other countries are consistent with our findings. Engel *et al* [4] evaluated 257 autopsied cases from Atlanta, GA, using 14 disease categories and found an overall agreement rate of 49.4%, and Cameron and McGoogan[5] reported 61% agreement when only 9 categories were used in a study of 1,152 cases in Scotland. The rate reported by Kircher and colleagues,[7] however, was unusually high (71% using 17 disease categories), based on 272 autopsies in Connecticut. Most recently, Modelmog *et al* [12] also found 70% agreement using 17 categories based on 1,023 autopsies performed in East Germany. These results, however, are based on deaths occurring in 1987 only, whereas the RERF series includes deaths occurring over a 40-year period.

Even when we used as general a distinction as neoplastic/non-neoplastic deaths, 24% of neoplasms were reported as non-neoplastic on the death certificate. This may, in part, reflect a reluctance in Japan to report cancer as the cause of death, but others also have reported detection rates for neoplastic disease between 70 and 80%.[3,4,6,9,12] Both liver cancer and leukemia were unusual among the various forms of cancer in that they were overstated on death certificates. For liver cancer, this was probably because metastatic cancers were erroneously reported as primary liver cancer. Since leukemia is known to be in excess among the exposed survivors, the high leukemia detection rates may not be surprising.

Our finding that the detection rates for non-neoplastic diseases were substantially worse than for neoplastic diseases was particularly discouraging because the opportunity for studying non-cancer incidence is limited since there are few population-based registries for these diseases.

Since many deaths occur at home or in nursing homes, particularly among the elderly, these deaths are of special interest. As expected, we, as well as others, [12] found death certificate accuracy to be considerably better for hospital than non-hospital deaths overall. We did not see this for all 12 disease categories, however. For cerebrovascular, heart and other circulatory, and respiratory diseases, there was no difference in accuracy between hospital and non-hospital deaths. It maybe that many of the patients dying at home with these diseases had been hospitalized shortly before death.

Epidemiologic studies which evaluate disease-specific time trends are especially sensitive to erroneous death certificate diagnoses and to changes in error rates. When new diagnostic technologies, such as the computed tomography scan or magnetic resonance imaging, are introduced, they improve the accuracy of diagnosis, and hence of death certificates, for some diseases. As a result, observed changes in reported mortality rates may be unreliable indicators of changes in the occurrence of particular diseases. Using the RERF autopsy series, Ron *et al* [15] have shown that, between 1976 and 1987, there was a significant rise in detection rates for certain cancers which could at least partly explain their reported increase in mortality. Studies evaluating associations between disease-specific mortality and geographic regions or populations with different risk factors are also affected by death certificate errors. If the levels of detection and confirmation vary for population groups, then comparisons of mortality rates can be severely biased. The inaccuracy of death certificate diagnoses also has important implications for health care planning. When expensive, high-technology equipment is acquired based on needs projected erroneously from death certificates, resources are misallocated. The same would be true for calculating optimal distribution of health and medical services.

Since the aim of most RERF studies is to evaluate the effects of radiation exposure, the finding that cause of death accuracy was not affected by radiation dose is of paramount importance because it suggests that dose effect estimates are not biased by death certificate inaccuracies. Sposto *et a1* [26] used data from the autopsy series to evaluate the effect of misclassification of cancer and non-cancer deaths on dose response. Assuming misclassification rates of 20% for cancer and 3% for non-cancer, they found that correcting cause of death misclassification reduced the non-cancer excess relative risk at 1 Gy by 21% and increased the cancer mortality excess relative risk at 1 Gy by 12%. But, although there was a difference in the point estimate of the risks due to misclassification, the recently reportedly radiation dose response demonstrated for non-cancer deaths was still observed. In fact, as long as misclassification did not depend on radiation dose, even a cancer misclassification rate as high as 36% did not alter this result.[26]

The inaccuracy of death certificate diagnoses has been described often, but as Glasser[27] points out, improving the accuracy of death certificate diagnoses is extremely difficult. Possible strategies for improving results obtained using death certificates include: obtaining additional information so that death certificate

diagnoses can be reviewed in individual studies; auditing death certificates from disease groups or populations which are known to have poor accuracy rates; incorporating statistical methods to adjust for diagnostic misclassification[26]; or restricting attention to diagnostic groups with acceptable detection and confirmation rates.[28]

Data based on death certificate diagnoses will continue to be used despite the fact that errors are frequent, because they are relatively complete, they usually are required by law, incidence data are difficult to collect, and more accurate mortality data are frequently not available. Thus, although it is important to be aware that the accuracy of death certificate diagnoses is low, it is also true that many studies based on them have been highly informative.

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