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A Historical Cohort Mortality Study of Workers Exposed to Asbestos in a Refitting Shipyard

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Abstract: To investigate the risks of developing asbestos-related diseases we conducted a historical cohort mortality study on 249 ship repair workers (90 laggers and 159 boiler repairers) in a single U.S. Navy shipyard in Japan. We successfully identified the vital status of 87 (96.7%) laggers and 150 (94.3%) boiler repairers, and, of these, 49 (56.3%) and 65 (43.3%) died, respectively, during the follow-up period from 1947 till the end of 1996. Our in-person interviews with some of the subjects clarified that asbestos exposure was considered to be substantially high in the 1950–60s, decreased thereafter gradually but remained till 1979 in the shipyard. The laggers, who had handled asbestos materials directly, showed a significantly elevated SMR of 2.75 (95% C.I.: 1.08–6.48) for lung cancer. The risk developing the disease was greater in the laggers after a 20-year latency (SMR=3.42). Pancreatic cancer yielded a greater SMR than unity (7.78, 90% C.I.: 2.07–25.19) in a longer working years group. Four laggers died from asbestosis. The boiler repairers, who had many chances for secondary exposure to asbestos and a few for direct exposure, showed no elevation of the SMR of lung cancer overall, but there was a borderline statistically significant SMR of 2.41 (90% C.I.: 1.05–5.45) in a longer working years group. One boiler repairer died from mesothelioma and four from asbestosis.

Key words: Asbestos, Historical cohort study, Lung cancer, Pancreatic cancer, Ship repair workers

Introduction

Asbestos is a general term describing a layer and some chain silicates which occur naturally in fibrous form. Since the late 19th century it has been widely used in many diverse ways in various industries owing to its chemical and physical properties, such as resistance to abrasion and heat, high tensile strength and flexibility. An article[1)] in 1968 which reported five cases of pleural mesothelioma and delineated extensively asbestos work in a naval shipyard elicited epidemiological investigations among shipyard workers in many countries. These subsequent studies[2–9)] have clarified that the excess deaths from lung cancer and malignant mesothelioma had a close association with asbestos exposure in shipyards.

No such studies have begun to date in Japan. However, statistically elevated SMRs of lung cancer were observed among the residents in some of the coastal cities having shipyards[10)], and high prevalences of parenchymal fibrosis and pleural abnormalities were found by chest X-ray among the 248 Japanese workers in a U.S. navy shipyard in a coastal city[11)]. These results implied an association between lung diseases and asbestos exposure in shipyards, which was recognized in other countries, and therefore necessitated a population-defined epidemiological survey. The present survey was a 30-year follow-up cohort study of all workers employed as laggers or boiler repairers in a single U.S. navy

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shipyard in Japan. This paper is the first report which evaluated the excess deaths due to asbestos exposure in a shipyard in Japan. In addition, this paper deserves attention because the study workplace was not a construction but a refitting shipyard, and the risk of asbestos-related diseases has not been fully investigated in such facilities in previous epidemiological studies in other countries[2–9].

Subjects and Methods

Subjects

Using various plant personnel records, we enrolled as study subjects all men (total 265) who were Japanese and employed as laggers (often designated "pipe coverers" or "insulators") or boiler repairers at any time from 1947 to the end of 1979 at a U.S. Navy shipyard in Japan. Since the initial six months after the hiring date was an apprenticeship, 16 men (2 laggers and 14 boiler repairers) who retired during this apprentice period were excluded from the study subjects. Accordingly, 249 remained for our cohort: 90 laggers and 159 boiler repairers. The year 1947, when we enumerated the cohort, was the shipyard's first year of operation and 1979 was the year after which extensive countermeasures against asbestos exposure were fully implemented in the shipyard.

Cause-of-death determination

The mortality follow-up of study subjects was performed for the period from 1947 until the end of 1996. With permission from the Japan Ministry of Justice and the relevant District Legal Affairs Bureaus, we ascertained the vital status of the enrolled subjects through official documents managed under the Family Registration Law. Subjects whose registered locality or current domicile was unknown were considered as lost to follow-up. For deceased persons, we obtained death certificates from the relevant District Legal Affairs Bureaus. The underlying causes of death were determined solely on the basis of death certificates, and coded according to the 9th International Classification of Diseases (ICD 9) by the results judged independently by three of the authors (N.K, Y.N, and R.M). In those who died from diseases in which asbestos exposure was suspected to contribute, such as heart failure, asbestosis, pneumonia, and cancers of the lung and mesothelium, we reviewed available hospital records to validate the causes of death. We also reviewed hospital records in a case with a retroperitoneal tumor to specify the disease site and cases with pancreatic cancer to examine whether mesothelioma or other diseases were misdiagnosed[12].

Calculation of person-years and SMR

The person-year experiences of individuals were computed on a monthly basis after the end of the six-month apprenticeship in the shipyard until the date of death or the end of the follow-up period (Dec 31, 1996). In case of the subjects whose vital status was not identified, we calculated their person-years only up to the date retired from the job[13], but could not calculate for those whose retirement date was unknown either.

To determine relative excess mortality rates, we calculated the standardized mortality ratios (SMRs) adjusted for age at risk and calendar year, in each 5-year strata, using the mortality rates among the Japanese male population every five years from 1950 to 1995[14]. The confidence intervals of SMRs were estimated by the normal approximation of the distribution for the expected cases greater than 20. If not, the intervals were calculated by the method[15] to obtain the narrowest confidence intervals based on the exact probabilities of the Poisson distribution. The intervals were shown at the 95% significant level. Because mortality rates from asbestosis, malignant pleural mesothelioma and retroperitoneal tumor were not consistently tabulated in the Vital Statistics of Japan during the entire follow-up period, we used instead those rates of pneumoconiosis (ICD 9; 500–508), malignant neoplasm of pleura (ICD 9; 163) and malignant neoplasms of peritoneum and retroperitoneum (ICD 9; 158), respectively. Accordingly, the SMRs of these diseases should be underestimated in the present study.

To investigate the effect of cumulative asbestos exposure on the mortality from the diseases of concern, we calculated SMRs in two subgroups based on the number of working years in the shipyard. Person-years of each subject contributed to the first subgroup, members of which worked up to an arbitrary limit (12 years for laggers and 15 years for the boiler repairers), and those whose person-years exceeded that limit comprised the second subgroup. Deaths were assigned to the final attained subgroup. The confidence intervals of these SMRs were obtained in the same way stated above but were shown at the 90% significant level.

In-person interviews

We conducted in-person interviews with some of the study subjects using a structured questionnaire by four of the authors (N.K., Y.N., R.S. and S.K.). The questions regarded job operations, asbestos materials used, countermeasures taken against asbestos exposure in the shipyard, and histories of smoking habits and diseases. This interview study was conducted in the early 1995 and was limited to the subjects who had retired from the shipyard. This limitation was applied from a practical point of view. It seemed that retired persons would feel more free to answer our interview than active workers. In addition, information that we mainly needed was that before the year 1980 when countermeasures against asbestos exposure were finalized. When a subject was deceased, we interviewed his relatives using a brief questionnaire asking smoking habits and disease histories of the subjects. In-person interviews were tried for 68 laggers (27 subjects and 41 relatives) and 114 boiler repairers (58 and 56, respectively).

Results

Demographic features of study subjects

Table 1 shows the demographic features of the subjects by job category. Among the 90 enrolled laggers, there were two subjects whose vital status and retirement date from the job were not identified. The remaining 88 subjects, 87 whose vital status was successfully identified and one followed only up to the retirement date, added the person-years of observation up to 2,623. A total of 49 (56.3%) had died during the follow-up period. The 88 contributors to the person-year data began to work as laggers at a mean age of 36.8, worked for an average of 10.9 years from the date assigned to the job till the end of 1979, and were followed for approximately 30.3 years. Half were assigned to the job by 1952. From the in-person interviews we estimated that 80.5% of the study laggers had a smoking history. With regard to the boiler repairers, the identified rate (94.3%) of vital status and proportion (43.3%) of those deceased during the follow-up period were slightly lower than in the laggers. But the 4,683 person-years of observation was 1.8 times greater than that in the laggers, which reflected the difference in the numbers of the enrolled subjects between the two groups. On average, the boiler repairers started their job three years younger than the laggers and worked for two years longer than did the laggers. Half of the boiler repairers were assigned to the job by the year 1952, and 84.0% had a smoking history.

Table 1. Demographic characteristics of study subjects by job category

	Laggers		Boiler repairers	
Subjects enrolled	90		159	
Subjects whose vital status and retirement data from the job not identified	2 (2.2%)		3 (1.9%)	
Contributors to person-years	88 (97.8%)		156 (98.1%)	
Total person-years of observation	2,623		4,683	
Subjects whose vital status identified	87 (96.7%) [1]		150 (94.3%) [1]	
Deceased subjects	49 (56.3%) [2]		65 (43.3%) [2]	
For contributors to person-years	mean	SD	mean	SD
Age when assigned to the job	36.8	10.4	33.5	10.1
Total years working at the job till the end of 1979	10.9	9.1	12.7	9.7
Years of follow-up	30.3	11.4	30.3	12.7
	alive	deceased	alive	deceased
Potential subjects for interview	27	41	58	56
Subjects interviewed successfully	23 (80.9%)	32 (78.0%)	48 (82.8%)	49 (87.5%)
Prevalence of current smokers	6 (26.1%) [3]	–	17 (35.4%) [3]	–
Prevalence of ex-smokers	15 (65.2%) [3]	–	22 (45.8%) [3]	–
Prevalence of ever smokers, testified by relatives	–	23 (71.9%) [3]	–	43 (87.8%) [3]
Estimated prevalence of subjects having a smoking history among the contributors to person-years	80.5% [4]		84.0% [4]	

[1] percentage among the subjects enrolled. [2] percentage among the subjects whose vital status identified. [3] percentage among the subjects successfully interviewed. [4] $((0.261 + 0.652) \times (88 - 49) + (0.719 \times 49))/88$ and $((0.354 + 0.458) \times (156 - 65) + (0.878 \times 65))/156$ for the laggers and boiler repairers, respectively.
–: data not obtained.

Table 2. Cause-specific SMRs for laggers by duration of employment

Underlying cause of death	Overall			less than 12 years			12 years and more		
	Obs	SMR	95% C.I.	Obs	SMR	90% C.I.	Obs	SMR	90% C.I.
All causes	49	1.22	0.92 – 1.61	23	1.04	0.72 – 1.47	26	1.43	1.03 – 1.98
Tuberculosis	0	0.00	0.00 – 3.08	0	0.00	0.00 – 3.55	0	0.00	0.00 – 7.90
Malignant neoplasms	15	1.43	0.84 – 2.36	7	1.29	0.66 – 2.40	8	1.57	0.89 – 2.85
Esophagus	1	1.93	0.10 – 11.13	0	0.00	0.00 – 11.09	1	4.05	0.43 – 20.06
Stomach	5	1.41	0.55 – 3.32	4	2.12	0.92 – 4.78	1	0.60	0.06 – 2.97
Rectum, rectosigmoid junction and anus	1	2.48	0.13 – 14.25	0	0.00	0.00 – 14.06	1	5.24	0.55 – 25.94
Pancreas	2	3.94	0.70 – 14.36	0	0.00	0.00 – 11.93	2	7.78	2.07 – 25.19
Retroperitoneum	0	0.00	0.00 – 121.42	0	0.00	0.00 – 166.33	0	0.00	0.00 – 249.50
Trachea, bronchus and lung	5	2.75	1.08 – 6.48	2	2.30	0.61 – 7.46	3	3.15	1.16 – 8.37
Pleura	0	0.00	0.00 – 289.54	0	0.00	0.00 – 427.71	0	0.00	0.00 – 427.71
Prostate	1	4.37	0.22 – 25.14	1	9.35	0.98 – 46.30	0	0.00	0.00 – 24.54
Urinary bladder	0	0.00	0.00 – 22.80	0	0.00	0.00 – 37.43	0	0.00	0.00 – 35.22
Leukemias	0	0.00	0.00 – 20.91	0	0.00	0.00 – 29.94	0	0.00	0.00 – 37.43
Heart diseases	9	1.49	0.74 – 2.86	5	1.55	0.75 – 3.26	4	1.42	0.62 – 3.20
Cerebrovascular diseases	5	0.58	0.23 – 1.38	2	0.43	0.11 – 1.38	3	0.77	0.28 – 2.05
Non-malignant respiratory diseases	11	2.75	1.44 – 4.95	3	1.45	0.53 – 3.87	8	4.12	2.33 – 7.47
Pneumonia	3	1.33	0.36 – 3.91	0	0.00	0.00 – 2.99	3	2.14	0.78 – 5.68
Asthma	0	0.00	0.00 – 8.25	0	0.00	0.00 – 11.74	0	0.00	0.00 – 14.90
Asbestosis	4	133.33	45.53 – 343.57	1	71.43	7.50 – 353.86	3	187.50	68.88 – 498.31
Accidents and adverse effects	4	2.33	0.80 – 6.01	3	2.90	1.07 – 7.72	1	1.46	0.15 – 7.25

Obs: observed deaths, SMR: standardized mortality ratio, C.I.: confidence intervals.

Cause-specific SMRs for the laggers

Table 2 shows the SMRs of selected causes of death with confidence intervals (C.I.) among the laggers overall and also divided by the length of working years till the end of 1979. For all subjects, the total deaths of 49 corresponded to an SMR of 1.22 with a 95% C.I. of 0.92–1.61. There were 15 cancer deaths. Of these 15, site-specifically, five workers died from lung cancer and the SMR of 2.75 was significantly higher than the null value. There were two cases of pancreatic cancer but the SMR was not statistically elevated. A review of hospital records revealed that both cases were diagnosed histologically: one had an autopsy and another had had surgery for the disease. None died from malignant mesothelioma. Deaths caused by non-malignant respiratory diseases, including four asbestosis cases, showed a statistically elevated SMR of 2.75, whereas heart diseases and cerebrovascular diseases did not. In an analysis according to duration of employment, the diseases, whose SMRs increased statistically at the 90% significant level only in the longer working years group, were lung cancer, pancreatic cancer and non-malignant respiratory diseases. These results suggested that the possibility of developing such diseases became greater with increases in duration of asbestos exposure.

Cause-specific SMRs for the boiler repairers

Table 3 tabulates cause-specific SMRs of selected diseases for the boiler repairers. Overall analysis showed that the SMRs of retroperitoneal tumor and malignant pleural mesothelioma were statistically higher than the null value. Both of these cases were in the longer working years group. We could not specify the disease site of the retroperitoneal tumor because of unavailability of hospital records. Four subjects died from asbestosis and one of them was found to have a large cell carcinoma in the lung by autopsy. Non-malignant respiratory diseases including these asbestosis cases showed a statistical elevation of SMR. As for lung cancer, the SMR in overall analysis did not deviate statistically from the null value, but the SMR of 2.41 in the longer working years group showed a borderline statistical significance (90% C.I.: 1.05–5.45).

Deaths from lung cancer and malignant pleural mesothelioma

Profiles of the subjects who died from lung cancer and malignant pleural mesothelioma are presented in Table 4. Hospital records available for histological diagnosis could be obtained in seven of ten lung cancer cases, which disclosed that two were squamous cell carcinomas and five adenocarcinomas. In the subject with malignant pleural

Table 3. Cause-specific SMRs for boiler repairers by duration of employment

Underlying cause of death	Overall			less than 15 years			15 years and more		
	Obs	SMR	95% C.I.	Obs	SMR	90% C.I.	Obs	SMR	90% C.I.
All causes	65	1.23	0.97 – 1.57	35	1.37	1.03 – 1.82	30	1.11	0.81 – 1.50
Tuberculosis	2	1.09	0.19 – 3.99	2	1.47	0.39 – 4.77	0	0.00	0.00 – 6.34
Malignant neoplasms	19	1.23	0.77 – 1.94	10	1.46	0.87 – 2.49	9	1.05	0.58 – 1.82
Esophagus	1	1.33	0.07 – 7.64	1	2.98	0.31 – 14.74	0	0.00	0.00 – 7.18
Stomach	4	0.82	0.28 – 2.11	4	1.72	0.75 – 3.88	0	0.00	0.00 – 1.17
Rectum, rectosigmoid junction and anus	1	1.69	0.09 – 9.71	0	0.00	0.00 – 11.26	1	3.06	0.32 – 15.15
Pancreas	0	0.00	0.00 – 4.78	0	0.00	0.00 – 9.18	0	0.00	0.00 – 6.48
Retoroperitoneum	1	23.81	1.21 – 137.05	0	0.00	0.00 – 115.15	1	58.82	6.18 – 291.41
Trachea, bronchus and lung	5	1.83	0.72 – 4.33	1	0.93	0.10 – 4.63	4	2.41	1.05 – 5.45
Pleura	1	55.56	2.83 – 319.78	0	0.00	0.00 – 427.71	1	100.00	10.50 – 495.40
Prostate	0	0.00	0.00 – 12.85	0	0.00	0.00 – 28.78	0	0.00	0.00 – 22.85
Urinary bladder	1	4.57	0.23 – 26.28	1	11.36	1.19 – 56.30	0	0.00	0.00 – 22.85
Leukemias	1	3.34	0.17 – 19.25	1	6.67	0.70 – 33.03	0	0.00	0.00 – 19.96
Heart diseases	12	1.60	0.89 – 2.78	6	1.81	0.90 – 3.62	6	1.43	0.71 – 2.86
Cerebrovascular diseases	9	0.93	0.46 – 1.78	7	1.46	0.75 – 2.71	2	0.41	0.11 – 1.32
Non-malignant respiratory diseases	10	2.13	1.13 – 3.90	4	2.07	0.90 – 4.67	6	2.17	1.08 – 4.33
Pneumonia	3	1.15	0.31 – 3.38	3	2.97	1.09 – 7.89	0	0.00	0.00 – 1.88
Asthma	1	1.94	0.10 – 11.18	0	0.00	0.00 – 11.13	1	4.07	0.43 – 20.14
Asbestosis	4	80.00	27.32 – 206.14	1	55.56	5.83 – 275.22	3	93.75	34.44 – 249.16
Accidents and adverse effects	4	1.44	0.49 – 3.71	2	1.24	0.33 – 4.00	2	1.72	0.46 – 5.57

Among malignant neoplasms one died from gall bladder cancer and three from liver cancer were not listed. We could not calculate these SMRs because the national death rates of the cancer had not been published separately until 1965. Obs: observed deaths, SMR: standardized mortality ratio, C.I.: confidence intervals.

Table 4. Deaths from lung cancer and malignant pleural mesothelioma

Case	Job	Months under the job	Cause of death on death certificate	Histological diagnosis	Materials used for diagnosis	First year at job	Latent years	Age at death	Smoking history
1	L	9	L.C.	squamous cell carcinoma	sputum cytology	1950	41	87	yes
2	L	26	L.C.	adenocarcinoma	tissue materials at surgery	1968	26	57	yes
3	L	149	L.C.	unknown	medical records unavailable	1947	32	84	yes
4	L	198	L.C.	unknown	medical records unavailable	1951	20	66	yes
5	L	300	L.C.	squamous cell carcinoma	autopsy	1950	37	76	yes
6	B	66	L.C.	adenocarcinoma	autopsy	1968	7	40	yes
7	B	183	L.C.	adenocarcinoma	autopsy	1950	26	72	yes
8	B	293	L.C.	adenocarcinoma	autopsy	1951	34	69	yes
9	B	294	L.C.	unknown	medical records unavailable	1950	44	82	yes
10	B	304	L.C.	adenocarcinoma	transbronchial lung biopsy	1951	42	77	yes
11	B	383	Malignant pleural mesothelioma	Malignant pleural mesothelioma	biopsy of the pleura	1951	41	71	yes

L: lagger, B: boiler repairer, L.C.: lung cancer.

mesothelioma, the diagnosis was supported by a histological finding of the pleura at biopsy, information of magnetic resonance imaging of the chest and his clinical picture. All but two subjects (#2 & 6) started their jobs around 1950 when asbestos exposure was assumed to be considerably high. In ten of 11 cases, more than 20 years had passed since the first exposure to asbestos in the shipyard till death. None of the relatives could affirmed that the subjects had never smoked.

Operations and asbestos materials in the shipyard

Our in-person interviews clarified the following. New ship construction work was never done and the employees had done solely ship repair work. Materials used, which contained asbestos in various concentrations, were insulating block, pipe sections, mattresses, cloth, felt, blankets and magnesia compound. The living subjects who were interviewed all stated that they used white asbestos more than brown, but not blue asbestos. They had never sprayed asbestos. Alternative non-asbestos materials such as glass fiber and rock wool for refitting had been increasingly used from the mid 1960s and replaced asbestos materials completely in 1975. However, asbestos still existed in 80% of the materials removed aboard ship even in 1980 because the majority of the ships repaired had been built before 1975. Sweeping and bagging of asbestos debris was initiated in the early 1950s and dust respirators were supplied since around 1970. Exhaust ventilation systems were not fully installed yet in the 1970s. It was after 1980 that impervious overalls were provided for workers handling asbestos materials.

On average, the laggers did 70% of their work aboard ship and the remainder in a shop. Their major work in which asbestos exposure occurred could be classified as: (1) removal and refitting of insulating asbestos materials constructed in boilers, which provided massive asbestos exposure of a short duration, particularly in removal, although the operation usually took 5 to 10 days monthly; (2) making mattresses shaped for pipes, flanges and valves with asbestos cloth and magnesia compound in shops, which produced large amounts of dust for short periods but was almost daily routine work till 1975; and (3) lagging and removing pipe sections in position around machinery, pipes, flanges and valves in all compartments aboard ship, which was not regular work but was frequently required. The laggers generally spent 70–80% of working time refitting pipes and making asbestos mattresses and 20–30% of their time refitting boilers.

The boiler repairers did 70% of their work aboard ship and 30% in a shop. Aboard ship they almost always worked near sites where removal of and refitting insulating materials were done by the laggers in boiler and engine rooms, and in shops adjacent to places where laggers were making asbestos mattresses. The former continued till 1980 and the latter till around 1970. Thus, the repairers were exposed to asbestos indirectly but continuously. In addition, they had limited opportunity for direct exposure to asbestos. One such opportunity was when refitting some of the more than 1,500 metal tubes installed in a boiler. The tubes, through which water ran for generating and cooling steam, themselves did not contain asbestos products. However, removal of the tubes frequently broke insulating materials near the places where the tubes were fixed and put the workers at direct risk for asbestos exposure, though this work was required only for 2 to 3 days a month. Another occasion was when overhauling a boiler casing lined with asbestos products in a shop, though this operation was done for only several days a year.

Discussion

We could identify the vital status of approximately 95% of the enrolled subjects for both jobs and observed that nearly half had died (Table 1). This percentage provided a satisfactory power to the present study to investigate the effects of asbestos exposure on mortality among the study subjects. We also interviewed retired workers and relatives of the deceased to clarify the operations performed, asbestos materials used in the shipyard, and the prevalence of smokers. In addition, we reviewed available hospital records and ascertained the underlying causes of death of the subjects who died from asbestos-related diseases and others of interest.

Asbestos materials used in this shipyard were considered to be chrysotile and amosite but not crocidolite. None of the retired subjects interviewed affirmed that crocidolite had been in use, and the reports[16–18] describing materials handled in the 1940s and the 1960s in the U.S. Navy shipyards at which the same types of naval vessels were repaired as in the study shipyard did not indicate that crocidolite had been used. In addition, the fibers of only chrysotile and amosite were detected in the lung tissue obtained at biopsy or surgery from four of our subjects by transmission electron microscopy (unpublished data). From our interview study, we could speculate that asbestos exposure among the workers had not changed substantially from the shipyard's first operation to the mid 1960s. It decreased thereafter gradually by the introduction of non-asbestos products, utilization of dust respirators and installation of exhaust ventilating systems, and terminated after 1980 when wearing impervious overalls was enforced for workers while handling asbestos materials. Measurement data of asbestos fiber concentrations in this shipyard were not published. However, we used the dust counts[19] (MPPCF: millions of particles per cubic foot) in the air measured in the 1960s in several U.S. Navy shipyards in the United States. Those dust counts corresponded to 8 to 38 asbestos fiber/cc in the boiler rooms and 8 to 70 fiber/cc in the environment while refitting and removing asbestos materials aboard ship, using the conversion factors of 3.0[20] fiber/cc for 1 MPPCF for pipe work and 1.4[21] for other work.

According to the demands of ship repair, as informed by the subjects interviewed, the workers always performed different operations and handled different types of asbestos materials under various work environments every few days or few weeks abroad ship or in shops. Workplaces were often confined to the spaces where exhaust ventilation systems were not installed or did not work efficiently. Consequently, the nature of ship repair work caused intermittent, short duration and massive exposure to asbestos in addition to continuous exposure. This was true particularly for the laggers, who handled asbestos materials directly in the shipyard. Under the same situations, the boiler repairers had many chances for secondary exposure to asbestos with a few chances for direct exposure.

In the present study, the SMRs of lung cancer showed greater values than unity at the 95% significant level of confidence intervals among the laggers overall and at the 90% level in the longer employment subgroups in both jobs (Tables 2 and 3). These SMRs fell in the range from 1.6 to 3.7, the range found in previous epidemiological studies[2–9] for lung cancer among shipyard workers.

However, a careful consideration of the obtained SMRs was needed because as a referent we used an external population, namely the Japanese male population. Different distributions of confounders between the referent and study populations could mislead conclusions. One of such confounders was a smoking habit. On the basis of the interview study, the prevalence of the laggers having a smoking history was estimated to be 80.5% and the boiler repairers 84.0% (Table 1). These estimates were comparable with or slightly higher than the prevalence of current smokers[22] in the 1960s and 1970s among the Japanese male population but around 20% higher than those in the 1980s and 1990s. Since our estimates included ex-smokers, true differences in smoking prevalence between the study and referent populations must be smaller than what it appeared to be. There was a possibility that these differences could contribute the magnitude of the observed SMRs of lung cancer but to limited extent. The epidemiological studies[23] documented that the relative risk of lung cancer caused by asbestos did not differ between smokers and non-smokers in addition to the interaction of smoking and asbestos. Individually, the deceased cases who died from lung cancer were all smokers (Table 4). However, most had started to work around 1950 when asbestos concentrations had been considerably high, and the dominant histologic type was adenocarcinoma, which has been reported to be associated less closely with smoking compared to squamous cell carcinomas in Japan[24].

As a referent, a regional population of study subjects is preferable to the general population for controlling geographic differences in disease incidence[25] which can distort SMRs. The data published by the local governments, however, frequently lack consistency with regard to tabulation of age classification and diseases concerned. This was the reason we could not use the regional mortality rates[26]. The SMRs of lung cancer, which we could calculate, however, were essentially the same as those based on the general mortality rates; 2.90 (95% C.I.: 1.14–6.85) and 1.92 (0.76–4.53) for all the laggers and boiler repairers, respectively.

The difference in the risk of developing lung cancer between the laggers and boiler repairers, and those between the subgroups in each job according to length of employment (Tables 2 and 3), corresponded well to the different extents of asbestos exposure. The laggers had many chances for direct exposure, while the boiler repairers had many chances for secondary exposure, and the longer the working years, the greater cumulative asbestos exposure became. When taking the period lapsed from the first exposure till the end of follow-up into consideration[27], the risk of lung cancer associated with asbestos would be greater. Otherwise, the association is suspicious. Assuming that the period was 20 years[27], our SMRs increased; 3.42 (95% C.I.: 1.35–8.08) and 1.92 (0.66–4.94), respectively, for the laggers and boiler repairers.

Consequently, the risk of developing lung cancer observed among the study subjects is causally associated with asbestos exposure in the shipyard.

Malignant mesothelioma is one of the well documented asbestos-associated cancers. The mortality of this tumor in the present study was zero (0/2623) per 10^5 person-years for the laggers and 21.4 (1/4683) for the boiler repairers. These occurrences were rather low compared to those previously reported values[5,7,28]. For example, 206 per 10^5

person-years for laggers and sprayers, 161 for boilermakers and 16 for unexposed workers in a naval shipyard in England[28]. These differences might be explained by an uncertainty of the result based on the small sample size in the present study or diversity of the dominant type of fibers used and work environments in different shipyards. It is likely, however, that our follow-up duration of 30 years on average was not long enough to be beyond the latent period for mesothelioma[27] and that the one-fourth to one-fifth times lower mortality rate of the disease in the general population in Japan[29] than in other countries contributed to the differences.

Of interest in this study was the elevated SMR of pancreatic cancer only in the longer working years subgroup among the laggers (Table 2). Peritoneal mesothelioma, metastatic lung cancer and abdominal carcinomatosis were often misdiagnosed as pancreatic cancer among asbestos workers[12], but both of our cases were verified histologically. One man worked for 20 years and another for 24 years as a lagger till the end of 1979. Of three cohort studies which had a large number of subjects with sufficient asbestos exposure giving a relative risk of lung cancer of more than 2, two studies[6, 30] did not show an increase in the SMR of pancreatic cancer. The remaining one[27] found a significant increase in the SMR of 2.81 on the basis of death certificates. However, the study also revealed that such a high SMR was reduced to 1.32 when underlying causes of death were reclassified using available hospital records, but suggested the possibility of some limited increase in pancreatic cancer among asbestos workers. That asbestos bodies existed in the pancreas was reported in a study[31] of various microscopically examined organs in 37 subjects who died from asbestosis, lung cancer and mesothelioma. Further observations are required whether asbestos exposure can increase the risk of development of pancreatic cancer.

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