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Cancer Morbidity of Foundry Workers in Korea

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Foundry workers are potentially exposed to a number of carcinogens. This study was conducted to describe the cancer incidence associated with employment in small-sized Korean iron foundries and to compare those findings to the Korean population. Cancer morbidity in 208 Korean foundries was analyzed using the Standardized Incidence Ratio (SIR) and Standardized Rate Ratio (SRR). Overall cancer morbidity in foundry workers (SIR=1.11, 95% confidence interval [CI]=1.01-1.21) was significantly higher than that of Korean general population. Lung cancer (SIR=1.45, 95%CI=1.11-1.87) and lymphohematopoietcic cancer (SIR=1.58, 95%CI=1.00-2.37) in production workers were significantly high compared to Korean general population. Stomach cancer in fettling (SRR=2.10, 95%CI=1.10-4.01) and lung cancer in molding (SRR=3.06, 95%CI=1.22-7.64) and in fettling (SRR=2.63, 95%CI=1.01-6.84) were there significant elevations compared to office workers. In this study, statistically significant excess lung cancer was observed in production workers comparing to Korean general population and office workers. Also, cancer morbidity of overall cancer, lung cancer and stomach cancer was significantly increased with duration of employment at ten and more years comparing to Korean general population. These findings suggest in causal association between exposure to carcinogens during foundry work and cancer morbidity.

Key Words: Foundry; Stomach Neoplasms; Lung Neoplasms; Lymphohematopietic Cancer

INTRODUCTION

Foundry workers are potentially exposed to a number of Group 1 carcinogens including crystalline silica, asbestos, polycyclic aromatic hydrocarbons (PAHs), benzene, formaldehyde, sulfuric acid mist and toxic metals (chromium, nickel, cadmium, etc.). Also the process of iron and steel founding itself has been listed as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC) since 1987 (1). The primary target organ of cancer for the above agents is the lung caused by crystalline silica, asbestos, chromium, cadmium, nickel and PAHs. Besides the lung, other target organs are the nasal cavity and sinuses caused by nickel compounds (2), the nasopharynx by formaldehyde (3), larynx and mesothelioma by asbestos (2), and leukemia by benzene and formaldehyde (3). Considering exposure to carcinogens which has limited or suggestive evidence to cause cancer, several kinds of cancer excess is expected in foundry workers. For example, gastrointestinal cancer caused by asbestos (2), liver cancer by trichloroethylene (4, 5), skin and bladder cancer by PAHs (3), prostate and kidney cancer by cadmium (2), and non-Hodgkin's lymphoma by benzene (3). Actually these kinds of cancer excess in foundry workers were identified through many epidemiologic studies (6-13). That is, a number of cancer excess are expected among foundry workers. However besides the lung cancer, excess in other cancers among foundry workers is still controversy.

In Korea, the number of foundries is continually decreasing because Korean workers avoid foundry work, perceiving it to be "3D" (Difficult, Dirty, and Dangerous). Now many of the remaining workers are older Koreans and immigrant workers in small scale companies. Just two health effect studies have been conducted on foundry workers in Korea. One was a lung cancer morbidity study using health insurance data which observed excess lung cancer (odds ratio [OR]=10.04, 95% confidence interval [CI]=3.95-25.55) (14) and the other was a pneumoconiosis prevalence study in 950 foundry workers which observed 35 pneumoconiosis cases (3.7%) classified as stage 1/0 or more advanced in the International Labor Organization (ILO) classification (15). Recently the Korea Labor Welfare Corporation (KLWC), which is exclusive provider of worker's compensation (excluding government employees, professional soldiers and educational staffs), approved compensation for 15 cases of occupational cancer (10 lung cancer; 3 lymphohematopoietic cancer, 1 laryngeal cancer and 1 malignant mesothelioma) in foundry workers (16). Among 3 lymphohematopoietic cancers, 2 cases were exposed to benzene formed by pyrolysis of benzene sulfonic acid.

As mentioned above, many kinds of cancer excess in foundry

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workers are expected and actually identified by previous epidemiologic studies. Therefore this study did not target specially designated cancers. This investigation was conducted to describe the cancer incidence associated with employment in Korean iron foundries and to compare those findings to the Korean population. The study also estimated exposure-cancer morbidity associations through cancer incidence comparison between production and office workers in foundry.

MATERIALS AND METHODS

Data collection and cohort definition

To construct the iron foundry workers' cohort, authors mailed to the employers of 388 iron foundries (industry code is 2731 by the Korea Standard Industrial Classification) which grasped by the company list reported to the Ministry of Labor (MOL) from each companies. Authors requested employers to hand in personal and occupational information about their employees for constructing the iron foundry cohort. Gathering information conducted from April to September, 2001.

Among 388 foundries, 208 companies provided paper records with the following worker information; name, Residence Registration Number (RRN; a unique 13-digit number assigned to all Koreans), dates of hiring and ending employment and individual work histories of previous employment (attached curriculum vitae of individual workers submitted at hire).

Finally the cohort was composed of 17,098 workers (men 14,611, women 2,487) from 208 small-sized iron and steel foundries who were working anytime between 1 January 1992 and 31 December 2000.

Cancer morbidity data was ascertained using the Cancer Registry maintained by the Korea Central Cancer Registry (KCCR). Study subjects were matched to the KCCR database using the RRN. Follow-up began for each worker at 1 January 1992 or the date of hire, whichever came later, and ended at 31 December 2005, on the date of cancer diagnosis, or on the date of death, whichever came sooner. The determination of vital status was based on mortality records of the Korea National Statistical Office (KNSO).

Reference cancer incidence rates for the Korean population were derived from the two published data. The numerator ascertained from the "Annual Report of the Korea Central Cancer Registry" for the period 1992 to 2005 (17), which showed the number of cancers by the kinds of cancer (classified by ICD-O-3), gender and 5-yr age group. And the denominator was gained from the registered population from 1992 to 2005 published by the KNSO (18), which showed the number of population by gender and 5-yr age group. Reference incidence rates of each cancer were calculated by gender, 5-yr age group and calendar years (1992-1996, 1997-2001, 2002-2005).

Exposure assessment

Individual exposure assessment could not be done in this study. In this study exposure assessment was done to classify job categories. Generally foundry work is classified into 5 categories: core making, molding, melting & pouring, shake-out and fettling (cleaning castings). However in this study job categories were just classified two groups (production and office work) when calculating Standardized Incidence Ratios (SIR) with reference to Korean general population. It was just because 1) small numbers of cancers hampered statistical power, especially when classified in many strata, and 2) some workers in this cohort had worked in more than 2 job categories at the same time and, in small-sized companies they have not worked in the separate locations according to the job categories. Thus the workers have been exposed to similar hazards regardless of job categories, as was demonstrated in previous study of foundry working environments in Korea (19-21). We analyzed Standardized Rate Ratio (SRR) with reference to office workers by 4 job areas: 1) molding & core making, 2) melting & pouring, 3) fettling and 4) mixed/unknown workers with unknown job categories including in previous employment or maintenance work involving many job locations. Job Area was classified as the longest-held job during their foundry work. Some workers worked in more than 2 job areas with the same durations, which cases were classified as each job areas.

Statistical analyses

A classification table for Poisson Regression analysis of cancer morbidity was calculated using a Person Year and Mortality Computation Program (PAMCOMP) (22). Person-years of observation were jointly classified in 10 age group (20-24, 25-29, ..., 60-69), 3 calendar year (1992-1996, 1997-2001, 2002-2005), 2 job category (office, production). Classification was based on a 5 yr lag for all cancers.

Using expected numbers of cancers calculated by multiplying the person-years by the gender-, age-, calendar-year, and cancer-specific incidence rates of the Korean general population, which permitted calculation of indirectly standardized rate ratios.

Standardized rate ratios (SRRs) allowed unbiased comparisons across exposure and other descriptive variables. SRRs of the production workers adjusting sex, age and calendar year were calculated using office workers as the comparison group. Also, SRRs of the workers by 4 job area categories were calculated relative to office workers.

Ethics statement

This work was approved by the Institutional Review Board (IRB) of Dongguk University Ilsan Hospital (IRB SOP ver4.0_20100401: 2010-1-48).

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RESULTS

Demographics

The study population of 17,098 workers was followed for a total of 183,170 person-years. Non-office workers (melting, pouring, molding, shake out, fettling and maintenance) comprised about 77% (140,791 P-years) of the cohort. Workers whose job was in an office (including sales and research) contributed 23% (42,379 P-years) of observation. The mean age at entering a foundry for the first time was 26.0 yr (33.0 yr at preset foundry) and more than half (52.1%) were firstly hired between ages 20 and 30 yr (Table 1).

Standardized Incidence Ratio (SIR) with reference to Korean general population

There were 485 cancers (men 421 cases, women 64 cases) incident during 1992-2005 (in approximately 2.8% of this cohort). Among the 485 cases, authors analyzed the SIR and SRR for cancer sites with 3 or more cases to ensure statistical power at least.

In production workers the morbidities of overall cancer (SIR=1.14, 95%CI=1.03-1.26), stomach (SIR=1.16, 95%CI=0.94-1.42), gall bladder & external hepatic duct (SIR=1.47, 95%CI=0.78-2.52), lung (SIR=1.45, 95%CI=1.11-1.87), cervix in women SIR=1.92, 95%CI=0.92-3.52), ovary in women (SIR=1.39, 95%CI=0.16-5.03), prostate in men (SIR=1.26, 95%CI=0.50-2.59), kidney & renal pelvis (SIR=1.12, 95%CI=0.51-2.13), leukemia (SIR=1.48, 95%CI=0.74-2.66), non-Hodgkin's lymphoma (SIR=1.84, 95%CI=0.95-3.21) and lymphohematopoietic cancer (SIR=1.58, 95%CI=1.00-2.37) were high compared to the Korean general population. Especially the incidence of overall cancer, lung cancer and lymphohematopoietic cancer were significantly elevated in production workers. Also, non-Hodgkin's lymphoma was significantly elevated in male production workers (SIR=2.01, 95%CI=1.04-3.52) (Table 2).

In office workers, the morbidities were greater than expected for colo-rectal cancer (SIR=1.17, 95%CI=0.56-2.14), gall bladder & external hepatic duct (SIR=1.13, 95%CI=0.13-4.08), pancreas (SIR=1.23, 95%CI=0.14-4.43), larynx (SIR=3.23, 95%CI=0.65-9.43), kidney & renal pelvis (SIR=1.17, 95%CI=0.13-4.22), urinary bladder (SIR=2.23, 95%CI=0.60-5.72), leukemia (SIR=1.61, 95%CI=0.32-4.71), non-Hodgkins' lymphoma (SIR=1.95, 95%CI=0.39-5.69) and lymphohematopoietic cancer (SIR=1.69, 95%CI=0.62-3.68), but statistically non-significantly increased (Table 2).

Overall cancer morbidity in relation to employment duration (calculated with a 5 yr lag) significantly increased with duration of employment from an SIR=1.03 at less than ten years to an SIR=1.22 (95%CI=1.07-1.37) at ten and more years. Stomach and lung cancer morbidity also significantly increased with duration of employment from SIR=0.87 and SIR=1.12 at less than 10 yr to SIR=1.35 (95%CI=1.05-1.71) and SIR=1.66 (95%CI=1.20-2.24) at ten and more years. Also, lymphohematopoietic cancer morbidity also significantly increased with duration of employment from SIR=1.27 at less than ten years to SIR=1.81 (95%CI=1.01-2.99) at ten and more years (Table 3).

Standardized Incidence Rate Ratio (SRR) of production workers with reference to office workers

Compared to office workers, production workers exhibited increased morbidity of all cancer (SRR=1.26, 95%CI=0.98-1.61), stomach (SRR=1.89, 95%CI=1.07-3.33), liver (SRR=1.70, 95%CI=

Table 1. General characteristic of foundry workers

	Production workers		Office workers		Total	
	No.	%	No.	%	No.	%
No. of workers	13,100	76.7	3,998	23.3	17,098	100.0
Gender						
Men	11,793	90.0	2,818	70.5	14,611	85.5
Women	1,307	10.0	1,180	29.5	2,487	14.5
Age (yr) in 2001						
20-29	1,801	13.7	939	23.5	2,740	16.0
30-39	2,861	21.8	1,297	32.4	4,158	24.3
40-49	4,249	32.4	967	24.2	5,216	30.5
50-59	2,907	22.3	568	14.2	3,475	20.4
60≤	1,282	9.8	227	5.7	1,509	8.8
Mean±S.D.	44.2±11.4*		39.6±11.3*		43.1±11.5	
Year first employed at foundry						
≤1979	5,321	40.6	1,513	37.8	6,834	40.0
1980-1989	4,817	36.8	1,293	32.4	6,110	35.7
≥1990	2,962	22.6	1,192	29.8	4,154	24.3
Age (yr) at first employed in foundry						
<20	2,778	21.2	829	20.7	3,607	21.1
20-29	6,550	50.0	2,358	59.0	8,908	52.1
30-39	2,776	21.2	627	15.7	3,403	19.9
40≤	996	7.6	184	4.6	1,180	6.9
Mean±S.D.	26.0±10.8*		23.3±10.0*		25.9±10.7	

*P<0.01.

Table 2. Cancer morbidity (SIR) by gender and job (Reference: Korean general population)

	Men			Women			Total		
	Office	Production	Total	Office	Production	Total	Office	Production	Total
Person-years	30,492	126,395	156,887	11,887	14,396	26,284	42,379	140,791	183,170
All cancers									
No.	63	358	421	13	51	64	76	409	485
SIR	0.97	1.13	1.11	0.93	1.19	1.13	0.96	1.14	1.11
95%CI	0.74-1.24	1.02-1.26	1.00-1.22	0.50-1.60	0.89-1.57	0.87-1.44	0.76-1.21	1.03-1.26	1.01-1.21
Esophagus									
No.	0	7	7	0	0	0	0	7	7
SIR	-	0.95	0.79	-	-	-	-	0.94	0.78
95%CI	-	0.38-1.96	0.32-1.63	-	-	-	-	0.38-1.93	0.31-1.61
Stomach									
No.	13	89	102	1	7	8	14	96	110
SIR	0.82	1.15	1.10	0.62	1.26	1.11	0.80	1.16	1.10
95%CI	0.44-1.40	0.93-1.42	0.89-1.33	0.01-3.43	0.50-2.59	0.48-2.19	0.44-1.34	0.94-1.42	0.90-1.32
Colon(&)rectum									
No.	9	36	45	1	5	6	10	41	51
SIR	1.19	0.97	1.01	1.01	1.18	1.15	1.17	0.99	1.02
95%CI	0.54-2.25	0.68-1.35	0.74-1.35	0.01-5.60	0.38-2.76	0.42-2.50	0.56-2.14	0.71-1.35	0.76-1.35
Liver									
No.	8	58	66	0	2	2	8	60	68
SIR	0.63	0.92	0.87	-	0.78	0.64	0.60	0.91	0.86
95%CI	0.27-1.23	0.70-1.19	0.67-1.11	-	0.09-2.82	0.07-2.33	0.26-1.18	0.70-1.18	0.67-1.09
Gall bladder & external hepatic duct									
No.	2	10	12	0	3	3	2	13	15
SIR	1.43	1.44	1.44	-	1.60	1.33	1.13	1.47	1.42
95%CI	0.16-5.17	0.69-2.65	0.74-2.52	-	0.32-4.66	0.27-3.88	0.13-4.08	0.78-2.52	0.79-2.34
Pancreas									
No.	2	6	8	0	2	2	2	8	10
SIR	1.34	0.81	0.90	-	2.92	2.43	1.23	0.99	1.03
95%CI	0.15-4.83	0.30-1.76	0.39-1.77	-	0.32-10.56	0.27-8.77	0.14-4.43	0.43-1.95	0.49-1.89
Larynx									
No.	3	3	6	0	0	0	3	3	6
SIR	3.28	0.65	1.08	-	-	-	3.23	0.64	1.07
95%CI	0.66-9.57	0.13-1.89	0.39-2.35	-	-	-	0.65-9.43	0.13-1.88	0.39-2.33
Lung									
No.	6	55	61	0	6	6	6	61	67
SIR	0.75	1.38	1.28	-	2.79	2.29	0.71	1.45	1.33
95%CI	0.27-1.63	1.04-1.80	0.98-1.64	-	1.02-6.07	0.83-4.98	0.26-1.54	1.11-1.87	1.03-1.69
Breast									
No.	0	1	1	2	7	9	2	7	11
SIR	-	4.62	3.83	0.72	0.84	0.81	0.71	0.93	0.88
95%CI	-	0.06-25.72	0.05-21.32	0.08-2.61	0.34-1.73	0.37-1.54	0.08-2.58	0.40-1.84	0.42-1.62
Cervix									
No.	-	-	-	2	8	12			
SIR	-	-	-	1.22	1.92	1.75			
95%CI	-	-	-	0.14-4.42	0.92-3.52	0.90-3.06			
Prostate (Men), Ovary (Women)									
No.	0	7	7	2	2	4			
SIR	-	1.26	1.05	3.26	1.39	1.95			
95%CI	-	0.50-2.59	0.42-2.16	0.37-11.77	0.16-5.03	0.52-4.99			
Kidney & renal pelvis									
No.	1	9	10	1	0	1	2	9	11
SIR	0.64	1.20	1.10	7.06	-	1.54	1.17	1.12	1.13
95%CI	0.01-3.54	0.55-2.27	0.53-2.02	0.09-39.30	-	0.02-8.58	0.13-4.22	0.51-2.13	0.56-2.02
Urinary bladder									
No.	4	7	11	0	0	0	4	7	11
SIR	2.31	0.83	1.08	-	-	-	2.23	0.80	1.05
95%CI	0.62-5.92	0.33-1.70	0.54-1.93	-	-	-	0.60-5.72	0.32-1.65	0.52-1.87
Thyroid									
No.	0	4	4	2	1	3	2	5	7
SIR	-	0.65	0.53	0.75	0.19	0.38	0.49	0.44	0.45
95%CI	-	0.17-1.66	0.14-1.35	0.08-2.70	0.00-1.07	0.08-1.12	0.05-1.76	0.14-1.03	0.18-0.93

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Table 2. *(continued from the previous page)* Cancer morbidity (SIR) by gender and job (Reference: Korean general population)

	Men			Women			Total		
	Office	Production	Total	Office	Production	Total	Office	Production	Total
Leukemia									
No.	3	9	12	0	2	2	3	11	14
SIR	1.99	1.34	1.46	-	2.77	1.86	1.61	1.48	1.51
95%CI	0.40-5.82	0.61-2.55	0.76-2.56	-	0.31-9.99	0.20-6.73	0.32-4.71	0.74-2.66	0.82-2.53
Non-Hodgkin's lymphoma									
No.	3	12	15	0	0	0	3	12	15
SIR	2.31	2.01	2.07	-	-	-	1.95	1.84	1.86
95%CI	0.46-6.74	1.04-3.52	1.16-3.41	-	-	-	0.39-5.69	0.95-3.21	1.04-3.07
Lympho-hematopoietic cancer									
No.	6	21	27	0	2	2	6	23	29
SIR	2.05	1.59	1.67	-	1.47	1.01	1.69	1.58	1.60
95%CI	0.75-4.45	1.01-2.29	1.10-2.43	-	0.17-5.32	0.11-3.66	0.62-3.68	1.00-2.37	1.07-2.30

Table 3. Cancer morbidity (SIR) in production workers by job duration (Reference: Korean general population)

Job duration (yr)	Men		Women		Total	
	10>	10≤	10>	10≤	10>	10≤
Person-years	58,413	67,981	6,783	7,613	65,196	75,594
All cancers						
No.	129	229	19	32	148	261
SIR	1.03	1.20	1.00	1.35	1.03	1.22
95%CI	0.86-1.23	1.05-1.37	0.60-1.56	0.92-1.90	0.87-1.21	1.07-1.37
Esophagus						
No.	2	5	0	0	2	5
SIR	0.72	1.09	-	-	0.71	1.08
95%CI	0.08-2.60	0.35-2.53	-	-	0.08-2.58	0.35-2.51
Stomach						
No.	25	64	3	4	28	68
SIR	0.84	1.36	1.29	1.23	0.87	1.35
95%CI	0.54-1.23	1.05-1.73	0.26-3.78	0.33-3.16	0.58-1.26	1.05-1.71
Colon (& rectum)						
No.	16	20	0	5	16	25
SIR	1.06	0.91	-	2.05	0.95	1.03
95%CI	0.61-1.73	0.56-1.41	-	0.66-4.77	0.54-1.54	0.66-1.51
Liver						
No.	26	32	1	1	27	33
SIR	1.05	0.84	0.97	0.65	1.04	0.83
95%CI	0.68-1.54	0.57-1.18	0.01-5.42	0.01-3.64	0.69-1.52	0.57-1.16
Gall bladder & external hepatic duct						
No.	3	7	1	2	4	9
SIR	1.11	1.65	1.42	1.70	1.18	1.66
95%CI	0.22-3.25	0.66-3.40	0.02-7.91	0.19-6.14	0.32-3.01	0.76-3.15
Pancreas						
No.	2	4	0	2	2	6
SIR	0.68	0.90	-	4.82	0.63	1.23
95%CI	0.08-2.46	0.24-2.29	-	0.54-17.40	0.07-2.26	0.45-2.68
Larynx						
No.	0	3	0	0	0	3
SIR	-	1.04	-	-	-	1.03
95%CI	-	0.21-3.03	-	-	-	0.21-3.00
Lung						
No.	17	38	1	5	18	43
SIR	1.12	1.55	1.15	3.90	1.12	1.66
95%CI	0.65-1.79	1.09-2.12	0.02-6.40	1.26-9.09	0.66-1.77	1.20-2.24

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0.81-3.55), gall bladder & external hepatic duct (SRR=1.58, 95%CI=0.35-7.08), lung (SRR=2.91, 95%CI=1.25-6.80), breast (SRR=3.53, 95%CI=0.58-21.39), thyroid (SRR=1.98, 95%CI=0.29-13.58) and cervix cancer (SRR=1.29, 95%CI=1.17-1.42). Especially the incidence of lung, stomach and cervix cancers were significantly elevated in production workers compared to office workers

Table 3. *(continued from the previous page)* Cancer morbidity (SIR) in production workers by job duration (Reference: Korean general population)

Job duration (yr)	Men		Women		Total	
	10>	10≤	10>	10≤	10>	10≤
Breast						
No.	0	1	6	1	6	2
SIR	-	7.80	1.47	0.23	1.44	0.45
95%CI	-	0.10-43.38	0.54-3.21	0.00-1.30	0.53-3.14	0.05-1.64
Cervix						
No.			4	6		
SIR			1.88	1.94		
95%CI			0.51-4.82	0.71-4.22		
Prostate (Men), Ovary (Women)						
No.	2	5	0	2		
SIR	0.90	1.50	-	2.55		
95%CI	0.10-3.24	0.48-3.50	-	0.29-9.22		
Kidney & renal pelvis						
No.	3	6	0	0	3	6
SIR	0.98	1.35	-	-	0.91	1.27
95%CI	0.20-2.85	0.49-2.94	-	-	0.18-2.66	0.46-2.76
Urinary bladder						
No.	4	3	0	0	4	3
SIR	1.21	0.58	-	-	1.17	0.56
95%CI	0.32-3.09	0.12-1.70	-	-	0.31-2.99	0.11-2.65
Thyroid						
No.	1	3	0	1	1	4
SIR	0.34	0.92	-	0.40	0.18	0.70
95%CI	0.00-1.91	0.19-2.70	-	0.01-2.25	0.00-0.99	0.19-1.79
Leukemia						
No.	3	6	1	1	4	7
SIR	1.06	1.55	3.18	2.45	1.28	1.64
95%CI	0.21-3.11	0.57-3.37	0.04-17.69	0.03-13.63	0.34-3.27	0.66-3.37
Non-Hodgkins lymphoma						
No.	4	8	0	0	4	8
SIR	1.54	2.38	-	-	1.40	2.18
95%CI	0.41-3.93	1.02-4.70	-	-	0.38-3.58	0.94-4.30
Lympho-hematopoietic cancer						
No.	7	14	1	1	8	15
SIR	1.23	1.86	1.65	1.33	1.27	1.81
95%CI	0.49-2.53	1.02-3.12	0.02-9.15	0.02-7.42	0.55-2.50	1.01-2.99

(Table 4).

Standardized Incidence Rate Ratio (SRR) of production workers by Job Area

Overall cancer morbidity was not significantly elevated for workers ever assigned to non-office job categories except in unknown/mixed job. Only for stomach cancer in fettling (SRR=2.10, 95%CI=1.10-4.01) and in unknown/mixed (SRR=1.99, 95%CI=1.03-3.85) and lung cancer in molding (& core making) (SRR=3.06, 95%CI=1.22-7.64), in fettling (SRR=2.63, 95%CI=1.01-6.84) and in unknown/mixed (SRR=2.61, 95%CI=1.00-6.79) were there statistically significant elevations compared to office workers (Table 4).

DISCUSSION

This type of cohort with short follow-up periods and a high proportion of active workers exhibits a large healthy worker effect for cancer. All workers in this cohort were still actively employed at the start of their follow-up (in 1992) and about half were actively employed at the time of data collection (in 2001), thus were highly selected for good health. Also, only 4.6% workers (788 among 17,098 study subjects) were deceased at the end of follow-up. Also because foundry production work is much heavier than most other work, the healthy worker survival effect in production workers would be larger than in office workers (23). This would tend to diminish estimated exposure effects with internal comparisons and may partly explain the virtually identical cancer morbidity observed for office and production workers.

Observing small numbers of cancers was the major limitation of this study, limiting its statistical power. Thus SIR with reference to Korean general population was not analyzed according to the detailed job categories like molding, core making, melting, pouring, shake-out and fettling. Defining one group for all foundry production activities limited the interpretation of observed associations comparing to Korean general population. On the other hand, previous Korean studies (19-21) on the foundry working environment showed that the concen-

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Table 4. Cancer morbidity (SRR) in production workers by job area (Reference: office workers)

	Total production		Melting & pouring		Molding & core making		Fettling		Indistinctness	
	No.	SRR (95%CI)	No.	SRR (95%CI)	No.	SRR (95%CI)	No.	SRR (95%CI)	No.	SRR (95%CI)
All cancer	411	1.26 (0.98-1.61)	78	1.16 (0.84-1.61)	145	1.16 (0.87-1.53)	100	1.16 (0.86-1.57)	104	1.45 (1.08-1.96)
Stomach	96	1.89 (1.07-3.33)	16	1.34 (0.65-2.77)	29	1.60 (0.84-3.04)	28	2.10 (1.10-4.01)	26	1.99 (1.03-3.85)
Colon & rectum	41	0.94 (0.47-1.88)	9	0.99 (0.40-2.48)	11	0.59 (0.25-1.39)	12	0.99 (0.43-2.33)	10	1.02 (0.43-2.46)
Liver	60	1.70 (0.81-3.55)	16	1.90 (0.81-4.45)	21	1.62 (0.71-3.67)	10	1.01 (0.39-2.58)	13	1.63 (0.68-3.94)
Gall bladder & ext. hepatic duct	13	1.58 (0.35-7.08)	3	1.45 (0.24-8.68)	7	2.29 (0.46-11.41)	0	-	3	1.47 (0.25-8.83)
Pancreas	8	0.97 (0.20-4.65)	1	0.49 (0.04-5.38)	5	1.24 (0.11-13.68)	2	0.80 (0.11-5.77)	2	1.12 (0.16-8.06)
Larynx	4	0.29 (0.07-1.30)	0	-	2	0.40 (0.07-2.40)	0	-	2	0.68 (0.11-4.09)
Lung	61	2.91 (1.25-6.80)	10	1.84 (0.67-5.05)	22	3.06 (1.22-7.64)	15	2.63 (1.01-6.84)	15	2.61 (1.00-6.79)
Breast	8	3.53 (0.58-21.39)	2	8.06 (0.94-68.23)	1	6.18 (0.17-231.20)	1	3.88 (0.21-71.02)	4	5.71 (0.82-39.77)
Cervix	11	1.29 (1.17-1.42)-N	1	2.07 (0.17-24.94)	4	2.07 (0.22-19.68)	1	0.72 (0.06-9.55)	5	3.93 (0.63-24.65)
Ovary	2	0.31 (0.03-2.89)	0	-	1	0.22 (0.02-3.09)	0	-	1	0.82 (0.06-11.39)
Kidney & renal pelvis	9	0.94 (0.20-4.34)	0	-	5	1.34 (0.26-6.96)	1	0.48 (0.04-5.73)	3	1.44 (0.24-8.68)
Urinary bladder	7	0.38 (0.11-1.31)	1	0.24 (0.03-2.15)	5	0.74 (0.20-2.75)	1	0.20 (0.02-1.76)	1	0.25 (0.03-2.26)
Thyroid	5	1.98 (0.29-13.58)	1	2.88 (0.16-52.05)	1	1.24 (0.04-37.47)	3	4.93 (0.56-43.28)	1	1.51 (0.10-24.04)
Leukemia	11	0.97 (0.26-3.56)	0	-	3	0.81 (0.15-4.34)	4	1.26 (0.27-5.85)	4	1.28 (0.29-5.71)
Non-Hodgkin's lymphoma	12	0.90 (0.25-3.19)	2	0.69 (0.12-4.18)	5	1.06 (0.25-4.44)	3	0.81 (0.16-4.06)	3	1.02 (0.21-.5.08)
Lympho-hematopoietic cancer	23	0.91 (0.37-2.24)	2	0.37 (0.07-1.82)	8	0.91 (0.31-2.65)	7	1.01 (0.34-3.05)	7	1.16 (0.39-3.44)

trations of silica were similar across job areas because of the small number of workers working contiguous spaces.

Many previous studies of foundry workers have observed significantly elevated lung cancer (6, 9, 11, 12, 24). This study found lung cancer elevations in production workers. This might not reflect a difference in smoking rate between study subjects and Korean population. In this study, when we surveyed the smoking status of foundry workers actively working in 2001, the smoking rate of production workers (65.5%) was slightly lower than that of Korean men (69.9%) and office workers (67.5%) in 2001 (25). However smoking status was ascertained only in active workers in 2001 and further investigation of retired workers is needed to completely control the analysis for smoking. The increased lung cancer incidence can most plausibly be explained as the result of exposures to known carcinogens in the foundry environment, primarily freshly cleaved crystalline silica from fettling operations, carcinogenic metals from melting and fettling, and PAHs from pyrolysis products from hot molds.

In this study, production workers worked at 10 and more years exhibited significant excess of stomach cancer. Some previous studies (6, 8, 9, 11) showed elevation of stomach cancer in foundry workers. The known occupational risk factors of stomach cancer include asbestos, metalworking fluids and other oil mist (2, 26). Among some foundry work, workers in the fettling shop are exposed to these kinds of hazards besides silica and heavy metals. In this study, 28 of the 96 stomach cancer cases worked in a fettling shop, which was a significant excess compared to office work (Table 4).

Aromatic and halogenated organic solvents such as benzene, 1,2,4-trimethylbenzene, and trichlorofluoro-methane are released into the foundry environment especially during core making, molding, and casting (12). There is some evidence that occupational exposure to trichloroethylene (resin solvent), methylene chloride, toluene, and xylene might be associated with an increased risk for liver cancer (4, 5, 12). Thus the non-significant excess morbidity of liver cancer in production workers comparing to office workers in this study can not be bypassed. Just one previous study observed increased liver cancer in foundry workers (12). This liver cancer excess in production workers might also be caused by non-occupational factors such

as heavy alcohol drinking and the poor socioeconomic status of foundry workers in Korea. Foundry workers showed a high prevalence of abnormal non-specific hepatic enzyme elevation (28.5% of workers increased AST or ALT or γ-GTP) (15) compared to other Korean workers (4.7% of workers who got general health examination in 2001) (27). However in this study, based on national cancer incidence, the SIR of liver cancer was slightly lower than that of Korean general population. Thus more follow-up and detailed investigation of occupational and non-occupational factors needed.

In previous studies, bladder cancer risk in foundry workers was elevated inconsistently. Certain mold technologies may emit bladder carcinogens and in addition, phenols, cresols, and aldehydes in the foundry work atmosphere might act as tumor promoters (7). In this study, only 7 bladder cancers were observed in production workers but 4 cases of bladder cancer were observed in office workers, a non-significant elevation SIR (2.23) compared to the Korean general population. Further follow-up needed to clarify this result.

Excess kidney cancer has been observed in previous foundry study (13). Core and mold making and metal melting and pouring foundry operations entail potential exposure to metal dusts and fumes, to PAHs, and to other chemicals potentially causing kidney cancer. In this study, kidney cancer was slightly increased in both office and production workers comparing to Korean general population. The mean PAH concentration at 30 foundries among the 208 companies during in 2001 and 2002 was 27.28±3.07 μg/m^3 (GM±GSD) (15), which was higher than that of emission test workers at an automobile inspection company (6.01 μg/m^3) (28) and of workers in coal tar containing paint manufacturing (17.5 μg/m^3) (29) in Korea. Thus further follow-up is needed to identify the relationship between kidney cancer and foundry exposures to PAHs.

During the casting process in foundries, the cores and molds are subjected to intense heat from the molten metal. As a result, the organic resin binders undergo thermal decomposition and produce a number of complex organic compounds like derivatives of phenol, benzene, furan, formaldehyde, and diverse mercaptans. Green sand molds, which contain powdered high-sulfur coal as a constituent and are frequently used in Korean foundries, emit benzene. The mean benzene exposure level was 0.35 ppm in 30 of the 208 Korean foundries that were investigated in 2001 and 2002 in Gyeonggii and Incheon area and was 2.46 ppm in foundries in the Changwon area in Korea (15). Also, measuring formaldehyde at 30 foundries in Incheon area, the mean exposure level was 0.12 ppm at core making, 0.06 ppm at pouring and 0.05 ppm at molding. Thus foundry workers are frequently exposed to benzene and formaldehyde, known causes of lymphohematopoietic cancers. Previous studies have observed significant excesses of leukemia among foundry workers (11, 30). In this study, comparing to Korean population, significant excess of lymphohematopoietic cancers were observed in production and all workers. However, comparing to office workers, the SRR of lymphohematopoietic cancers was slightly decreased. Thus more follow-up and personnel exposure assessment needed to clarify these findings.

This study describes work-related cancer morbidity in small-scale Korean foundry operations in relation to the national population and demonstrates the importance of addressing issues of selection confounding, such as the healthy worker and survivor effects, in analyzing exposure health effects. The interpretation of these findings is hampered by the small numbers of cases and the limited exposure history available for individual workers. Statistically significant excess lung cancer was observed in production workers comparing to Korean general population and office workers. And stomach cancer in production workers were significant elevations comparing to office workers. Also, cancer morbidity of overall cancer, lung cancer and stomach cancer was significantly increased with duration of employment at ten and more years comparing to Korean general population. These findings suggest in causal association between exposure to carcinogens during foundry work and cancer morbidity. Special attention should be paid to this finding and detailed investigations are needed to identify the cause of these cancer excess.

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