Cancer Morbidity in Iron and Steel Workers in Korea

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Background *In the iron and steel industry, workers are potentially exposed to a number of carcinogens and are involved in a number of processes of a hazardous nature. The cancer morbidity of iron and steel workers from modern plants in a developing country is described.*

Methods *Cancer morbidity at two Korean iron and steel complexes was analyzed using Poisson regression methods. Work histories were merged with the national cancer registry for 44,974 workers who were followed from 1988–2001.*

Results *Four hundred sixty-four cancers, in 1% of the population, were diagnosed over 14 years. Based on national cancer rates, the cohort exhibited a healthy worker effect for all cancer (SIR = 0.87, 95% CI = 0.79–0.95) reflecting relative good health, particularly for lung cancer (SIR = 0.58, 95% CI = 0. 04–0.82), stomach cancer (SIR = 0.78, 95% CI = 0.64–0.93), and liver cancer (SIR = 0.83, 95% CI = 0.68–1.01). Lung cancer morbidity was significantly elevated at the affiliated plants versus the parent plants (SRR = 2.35, 95% CI = 1.07–4.92), and all-cancer morbidity was significantly elevated for maintenance workers compared to office and production workers (SRR = 1.27, 95% CI = 1.00–1.60). Lymphohematopoietic cancer incidence was higher in the coke plants (SRR = 3.46, 95% CI = 1.02–8.91) and stomach cancer incidence was higher in the maintenance departments (SRR = 1.66, 95% CI = 1.05–2.56).*

Conclusions *This recent steelworker cohort exhibits possible excess cancer morbidity in some processing areas. Further follow-up of this cohort and alternate study designs such as case-control study will be needed to elucidate the relationship of exposure and health risks of iron and steel workers.* Am. J. Ind. Med. 49:647–657, 2006.
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KEY WORDS: iron and steel industry; lung cancer; lymphohematopoietic cancer; stomach cancer; coke ovens

INTRODUCTION

In the iron and steel industry, a variety of processes such as coke production, transformation of iron ore and scrap to molten metal, oxidization for purification, addition of alloying metals, pouring, and continuous-casting are involved in producing billets, blooms, and slabs. Subsequent steps include rolling, drawing, cutting, welding work. Workers in this industry are potentially exposed to a number of carcinogens including polycyclic aromatic hydrocarbons, acid mists, oil mists, and toxic metals (chromium, nickel, cadmium, etc.). Previous studies have observed significantly increased rates of cancer overall [Redmond et al., 1981] and excess lung cancer has been observed in coke plant

Abbreviations: SIR, standardized incidence ratio; SRR, standardized rate ratio; 95% CI, 95% confidence interval; KNSO, Korean National Statistical Office; KNCC, Korean National Cancer Center.

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The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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operations [Lloyd, 1971; Swaen et al., 1991; Chau et al., 1993; Xu et al., 1996a,b; Bye et al., 1998], in the pouring areas of the melt departments [Finkelstein and Wilk, 1990; Finkelstein et al., 1991; Moulin et al., 1993] and in furnace brick manufacture [Xu et al., 1996a,b]. Stomach cancer elevations have been reported in iron smelting, rolling mills, brick manufacture, and powerhouse activities [Xu et al., 1996a,b] and in coke production [Bye et al., 1998]. Elevated bladder cancer has been reported in some coke plant workers [Golka et al., 1999], but not others [Grimsrud et al., 1998]. Some studies have observed significantly increased kidney cancer in the blast furnace, coke-oven, and iron and steel industry workers [McCredie and Stewart, 1993; Mandel et al., 1995], but others have not [Mellemgaard et al., 1994].

In Korea, a large iron- and steel-making company was established in 1968 with relatively modern facilities and equipment and, thus, was likely to have exposed workers to lower levels of many hazardous agents than were present in previous studies, often at companies established in the late 1800s and early 1900s. An analysis of mortality in this Korean population has been reported elsewhere [Park et al., 2005]. This investigation was conducted to describe cancer incidence associated with employment in the modern Korean iron and steel industry and to compare cancer patterns in these industrial workers with the Korean population, which differs from western countries where most previous studies have been conducted. For example, the three leading cancers in Korean men in 1999 were stomach, liver, and lung (and bronchus) [Korea Central Cancer Registry, 2001a] while in the US, the three leading cancers were prostate, lung (and bronchus), and colon (and rectum) [National Cancer Institute, 2002].

MATERIALS AND METHODS

Cohort Definition and Data Collection

The employees studied belonged to one large company and 28 smaller affiliated subsidiaries as described previously [Park et al., 2005]. The parent company had two large iron and steel complexes in different locations with the same industrial processes, except for a stainless steel mill; they were established in 1968 (Parent Plant No. 1) and 1982 (Parent Plant No. 2). The 28 subsidiaries were involved only in coke production and in providing maintenance support for the parent company plants and were established between 1977 and 1997. (This same company has more than 1,000 additional subsidiaries that have some role in the iron and steel operations and management including dining, housing, and cleaning but work histories were not available from these sources).

The cohort was composed of all male Korean workers who had been employed in the study plants at any time between 1 January 1968 and 31 December 2001. Female workers were not included because they comprised only 4% of the workforce; most were in office jobs and very few in production and maintenance jobs. They were relatively young. Follow-up of the cohort began in 1988, when cancer diagnoses first became available from the national cancer registry and ended on 31 December 2001. The determination of vital status was based on employment and mortality records of Korean National Statistical Office as described previously [Park et al., 2005]. The company personnel department provided the worker's name, Residence Registration Number (RRN; a unique 13-digit number assigned to all Koreans), birth date, dates of hiring and ending employment, and individual work histories consisting of plant, department, and job classification assignments. More than 500 job titles were grouped into three categories—office, production, and maintenance. Workers employed at the parent plants in 1994 or later were asked by the company occupational physician for smoking information [Park et al., 2005]. Smoking histories obtained for 18,915 of 20,209 workers active in 1994 were compared with those of the Korean male population [Park et al., 2005].

Cancer morbidity data was ascertained using the Cancer Registry maintained by the Korean National Cancer Center (KNCC) [Korea Central Cancer Registry, 2001a], which recently has been estimated to have greater than 95% ascertainment of cancer morbidity status for the Korean people [Korea Central Cancer Registry, 2001b]. KNCC records include the 13-digit RRN, cancer occurrence date (strictly speaking, the first date of diagnosis), kinds of cancer (T-code: Topography), and pathologic findings (M-code: Morphology). Diagnoses are confirmed by pathologists at 180 individual hospitals participating in the Cancer Registry (in 2001) and are classified according to the International Classification of Disease for Oncology, second edition. In 2001, among 91,944 malignant cases reported by individual hospitals, 81,952 cases (89.1%) were based on pathologic findings [Korea Central Cancer Registry, 2003]. Study subjects were matched to the KNCC database using the RRN. Follow-up began for each worker at 1 January 1988 or the date of hire, whichever came later, and ended at 31 December 2001 or on the date of death, whichever came sooner. Reference cancer morbidity rates for the Korean population were derived from data compiled by the KNCC for the period 1988 to 2001.

Exposure Assessment

The production, maintenance, and other support departments where workers had been employed (n = 13) were classified into eight process categories: (1) quality control (product inspection), material handling, and construction, (2) iron production (ore preparation, sintering, blast furnace using iron ore and coke), (3) coke plants (including byproducts), (4) steel production (oxygen converter, continuous casting, and rolling), (5) stainless steel production (since 1989, only at Parent Plant No. 1), (6) cold mill and hot mill, (7) powerhouse, and (8) maintenance and repair (including central and plant-based). In most departments, workers could have worked in production, maintenance, or office job classifications. From work histories, a worker's cumulative duration of employment in each process category as a production or maintenance worker was calculated at each interval of follow-up.

According to company records, exposures to the following potentially carcinogenic materials occurred in one or more of the process areas: mineral dust, toxic metals (chromium [Cr^{6+}], nickel [Ni]), benzene, toluene, xylene, coal tar pitch volatile (CTPV), polycyclic aromatic hydrocarbons (PAHs), and H_2SO_4 (Table I). Some hazardous agents, such as Cr^{6+} and benzene, were present in many process areas. Air sampling measurements for known (Group 1) and probable (Group 2A) carcinogens classified by IARC (International Agency for Research on Cancer), probably representing worst case situations during 1994–2000, indicate that exposures for Cr^{6+} and nickel were quite low while for other carcinogens (benzene, H_2SO_4, CTPV, PAHs) exposures approached Korean TLV levels [Korean Ministry of Labor, 1998], where health effects might be expected (Table I). Prior to 1990, exposures were generally higher, especially in coke oven operations where investigations prior to 1990 led to extensive improvements in engineering controls.

The reported exposure data were classified by detailed process characteristics in more than 500 categories, which were not compatible with our department-based classification in just 8 broad process areas. The available work history did not provide worker-specific detail on time spent in specific process activities that could be readily linked to the air sampling results. Future study of this cohort may permit analyses by more detailed job-exposure.

Classification and Specification for Poisson Regression Models

A classification table for Poisson Regression analysis of cancer morbidity was calculated using a FORTRAN program developed previously [Park et al., 2002, 2005]. Person-years (538,174 in number) of observation were jointly classified in 10 age (<20, 20–24, 25–29, 30–34,... ,65+), 3 calendar (1988–1991, 1992–96, 1997–01), 4 plant (parent plant 1, parent plant 2, affiliates to plant 1, affiliates to plant 2), 3 job (office, production, or maintenance), and 5 employment

TABLE I. Carcinogen (IARC Group 1 or Group 2A) Concentration of Air Contaminants by Process Area at Parent Plant No. 1 Iron and Steel Complex During 1994–2000; Korea

Material (TLV[a])	Process area	Range of sample-means in process areas[b]
Benzene (1.0 ppm)	Coke plant	ND-0.938
	Coke plant (byproducts)	ND-0.753
	Coke plant (byproducts)	0.051–0.395(K)
	Coke plant (maintenance)	ND-0.64
	Maintenance (central)	ND-0.44
	Cold rolling mill	ND-0.09
	Powerhouse (waste water treatment)	ND-0.05
Hexavalent chromium (0.05 mg/m^3)	Cold rolling mill	ND-0.008
	Stainless steel mill	ND-0.004
CTPV (0.20 mg/m^3)	Coke plant	0.006-0.189
	Coke plant	ND-2.24 (K)
	Coke plant (maintenance)	ND-0.111
	Coke plant (byproducts)	ND-0.076
PAH (200 ug/m^3)	Coke plant	15.5–96.4 (K)
H_2SO_4 (1 ppm)	Cold rolling mill	ND-1.578
	Stainless steel mill	ND-0.350
	Stainless steel (maintenance)	ND-0.589
Ni(metal) (1.0 mg/m^3)	Maintenance (central)	ND-0.201
	Stainless steel mill	ND-0.033
	Quality testing	ND-0.020
	Steel production	ND-0.007

[a]Korean Ministry of Labor, Notice 1997–65 of Ministry of Labor: Exposure Limits of Chemicals and Physical Agents. Ministry of Labor, 1998.

[b]All samples taken by employer except for (K): by Korean Occupational Safety and Health Administration; all data based on personal samplers with 6 or more hours sampling time; ND = below limit of detection.

duration categories (0–1, 1–5, 5–10, 10–20, 20+ years), together with 5 levels of cumulative duration in each of the 8 process categories (0, 1–2, 2–5, 5–10, 10+ years). For terminated employees, follow-up was classified based on their final job and employment duration. Thus, short-term employees hired in the late 1960s could contribute many years of follow-up in the lowest duration category. The unit of follow-up was 10 days, that is, every 10-day interval of person-time was classified as described above. Plant was classified as ''plant where first hired,'' to address possible differential selection on health status at hire. Job was classified as ''current job,'' or ''most recent'' if no longer employed. Following an initial orientation period, job classification did not change for almost all workers; exceptions included workers who were moved at the recommendation of the parent company physician. Maintenance jobs included both skilled and non-skilled workers. Classification was based on a 10-year lag for all cancers except for lymphohematopoietic cancer (5-year lag).

Log-linear relative rate models in Poisson regression were evaluated for the effects of plant, job status, or employment duration; ever employed in the eight process areas; or in levels of process employment duration [Park et al., 2005]. Models were fit using Epicure software[23] and those with the largest decrease in deviance (i.e., decrease in −2log (likelihood) with addition of exposure terms) were considered to be ''best'' fitting. In some models, external indirect standardization on age and calendar time was accomplished by incorporating Korean cancer incidence rates (strictly speaking, cancer registration rates) as a multiplier of person-years; in other models, direct standardization was achieved by the stratification procedure in Epicure [Preston et al., 1993] in order to permit unbiased comparisons across classifying strata [Park et al., 2005]. Employment duration was included as a stratifying variable because of the declining relative mortality of the study population with duration [Park et al., 2005], indicative of a healthy worker survivor effect [Arrighi and Hertz-Picciotto, 1994].

RESULTS

Demographics

The study population of 44,974 workers was followed for 538,174 person-years. Workers from Parent Plant No. 1 comprised more than half of the cohort. Workers whose job was in an office, contributed the most observation time (330,863 P-years) followed by production (121,149 P-years) and maintenance (63,262 P-years). As reported previously [Park et al., 2005], in the parent plants the current smoking rate was similar across categories of job, and the overall smoking rate of study subjects in 1994 was about 15% lower than that of Korean male population in that year [Jee, 1999]. The proportion of current smokers among active employees dropped dramatically from 59.9% in 1994 to 14.4% in 2000 at Parent Plant 1, and from 55.4% to 33.3 % between 1997 and 2000 at Parent Plant 2 following an aggressive health promotion campaign [Park et al., 2005].

Cancer Morbidity by Plant, Job Class, and Employment Duration

There were 464 cancers incident during 1988–2001 (in approximately 1 % of the iron and steel cohort). All-cancer, and lung, stomach, and liver cancer morbidities were low significantly compared to the Korean general population (all-cancer SIR = 0.87, 95% CI = 0.79–0.95; lung Ca SIR = 0.58, 95% CI = 0.40–0.82; stomach Ca SIR = 0.78, 95% CI = 0.64–0.93; and liver Ca SIR = 0.83, 95% CI = 0.68–1.01) (Tables II–IV). Bladder and kidney cancer and lymphohematopoietic cancer morbidities in the entire cohort were non-significantly higher than those of Korean general population (bladder and kidney Ca: SIR = 1.24, 95% CI = 0.85–1.74 (Table III); lymphohematopoietic Ca SIR = 1.18, 95% CI = 0.83–1.60 (Table V)).

Parent plant No.1, comprising 61% of observation time, showed the same patterns of cancer morbidities as the entire cohort (Tables II–V), but an excess of brain cancer (non-significant) was observed only in Parent plant No.1 (Table V). Compared to the parent plants, overall cancer morbidity at the affiliated plants was marginally significantly higher (SRR = 1.22, 95% CI = 0.97–1.51) (Table II). Lung cancer in workers of affiliated plants, however, was considerably higher than that of the parent plants (SRR = 2.35, 95% CI = 1.07–4.92) (Table III).

Compared to office workers, workers in production jobs had slightly lower all-cancer morbidity (SRR = 0.89, 95% CI = 0.71–1.10), but compared to office and production workers, maintenance jobs had significantly increased cancer morbidity (SRR = 1.27, 95% CI = 1.00–1.60) (Table II). Liver and lung cancer morbidities of office workers were lower than those of the Korean general population (liver cancer SIR = 0.72, 95% CI = 0.51–0.97; lung cancer SIR = 0.60, 95% CI = 0.35–0.96) (Tables III and IV), but bladder and kidney cancer morbidity in office workers was higher (SIR = 1.36, 95% CI = 0.80–2.14). Bladder and kidney cancer morbidity in production jobs was non-significantly lower than in office workers (SRR = 0.79, 95% CI = 0.33–1.80). Lymphohematopoietic cancer was somewhat elevated in production workers (SIR = 1.36, 95% CI = 0.77–2.20) and was higher than in office workers (Table V). Stomach cancer morbidity in production jobs was lower than in the Korean general population (SIR = 0.63, 95% CI = 0.43–0.87), but was non-significantly elevated in maintenance jobs when compared with office and production workers (SRR = 1.40, 95% CI = 0.87–2.18) (Table II).

Overall cancer morbidity in relation to employment duration (calculated with a 10 year lag) suggested an

TABLE II. Cancer Morbidity (SIR, SRR) From All Cancer and Stomach Cancer in Korean Iron and Steel Workers

		All cancer			Stomach cancer		
External comparisons	P-years	N	SIR[a]	95% CI	N	SIR[a]	95% CI
All plants	538,174	464	0.87	0.79–0.95	114	0.78	0.64–0.93
Parent plant No.1	330,863	322	0.83	0.75–0.93	80	0.75	0.60–0.92
Parent plant No.2	97,154	40	0.90	0.65–1.21	9	0.76	0.37–1.37
Office workers	353,763	235	0.88	0.77–1.00	58	0.80	0.61–1.02
Production	121,149	142	0.77	0.65–0.91	32	0.63	0.43–0.87
Maintenance	63,262	87	1.06	0.85–1.29	24	1.05	0.68–1.52
Internal comparisons	P-years	N	SRR	95% CI	N	SRR	95% CI
Parent plant No.1	330,863	322	1.00		80	1.00	
No.1 affiliate	65,702	71	1.27	0.97–1.63	15	1.12	0.62–1.89
Parent plant No.2	97,154	40	1.02	0.71–2.42	9	1.01	0.37–1.37
No.2 affiliate	44,455	31	1.12	0.75–1.60	10	1.64	0.53–1.85
Affiliates versus parents[b]	110,157	102	1.22	0.97–1.51	25	1.28	0.80–1.97
Current Job							
Office	353,763	235	1.00		58	1.00	
Production	121,149	142	0.89	0.71–1.10	32	0.73	0.46–1.14
Maintenance	63,262	87	1.21	0.93–1.55	24	1.23	0.74–1.98
Maintenance[c]	63,262	87	1.27	1.00–1.60	24	1.40	0.87–2.18
Duration							
<1 yrs	296,901	121	1.00		32	1.00	
1–5 years	113,312	107	1.06	0.79–1.43	23	0.68	0.38–1.23
5–10 years	79,260	104	1.08	0.79–1.49	26	0.77	0.42–1.42
10–20 years	48,527	131	1.16	0.84–1.62	32	0.96	0.51–1.84
>20 years	174	1	1.23	0.07–5.77	1	4.56	0.24–25.79

Classifications based on a 10-year lag.
[a]Reference: Korean national population 1988–2001.
[b]Reference: parent plants nos. 1 and 2.
[c]Reference: office and production workers combined.

increasing (non-significant) trend (Table II). Liver cancer morbidity increased considerably with duration of employment from an SIR=0.42 at less than 1 year to an SIR = 1.16 at 10–20 years (data not shown); compared to employment duration with <1 year, liver cancer was highly significantly increased at 5–10 years (SRR = 4.41, 95% CI = 1.81–12.09) and at 10–20 years (SRR = 4.72, 95% CI = 1.93–13.21) (Table IV). Lung cancer morbidity appeared to consistently decline with increasing employment duration (Table III) and, at 10–20 years, was (non-significantly) reduced by half (SRR = 0.51, 95% CI 0.16–1.71). Bladder and kidney cancer morbidities showed no consistent trend with duration (Table III). Compared to employment duration <1 year, colorectal cancer was significantly elevated only at 1–5 years (SRR = 2.49, 95% CI = 1.07–6.37), (Table IV).

Cancer Morbidity by Working Process Area

Overall cancer morbidity was not significantly elevated for workers ever assigned to non-office work processes although Maintenance work was marginally significantly elevated (Table VI). Only for stomach cancer in Maintenance (SRR = 1.66, 95% CI = 1.05–2.56) and lymphohematopoietic system cancer in Coke Plant (SRR = 3.46, 95% CI = 1.02–8.91) were there significant elevations compared to all other workers. Other process areas possibly contributing to the overall excess of lymphohematopoietic cancer were the cold/hot mill and steel production areas. Small numbers of excess bladder/kidney cancer cases occurred in iron production, steel production, and powerhouse operations, and colorectal cases in maintenance and coke ovens, but none was individually significant.

Analyses of associations with duration worked in process areas were not feasible for most cancer outcomes owing to small numbers of cases. For stomach cancer (n = 56 in production or maintenance), a regression model with terms for duration in (a) maintenance, (b) powerhouse, and (c) stainless steel production revealed significantly elevated rates in the lowest duration category for maintenance and power house work, and substantially elevated rates in stainless steel, but involving only two cases (Table VII).

TABLE III. Cancer Morbidity (SIR, SRR) From Lung and Bladder and Kidney Cancer in Korean Iron and Steel Workers

		Lung cancer			Bladder and kidney		
External comparisons	P-years	N	SIR[a]	95% CI	N	SIR[a]	95% CI
All plants	538,174	30	0.58	0.40–0.82	30	1.24	0.85–1.74
Parent plant No.1	330,863	17	0.44	0.26–0.69	18	1.03	0.62–1.57
Parent plant No.2	97,154	2	0.72	0.12–2.21	3	1.59	0.39–4.11
Office workers	353,763	15	0.60	0.35–0.96	16	1.36	0.80–2.14
Production	121,149	11	0.59	0.31–1.01	9	1.06	0.51–1.90
Maintenance	63,262	4	0.52	0.16–1.20	5	1.30	0.46–2.79
Internal comparisons	P-years	N	SRR	95% CI	N	SRR	95% CI
Parent plant No.1	330,863	17	1.00		18	1.00	
No.1 affiliate	65,702	10	3.32	1.44–7.26	9	2.55	1.09–5.57
Parent plant No.2	97,154	2	1.53	0.24–5.63	3	1.03	0.23–3.24
No.2 affiliate	44,455	1	0.67	0.04–3.30	0	—	
Affiliates versus parents[b]	110,157	11	2.35	1.07–4.92	9	1.66	0.72–3.54
Current job							
Office	353,763	15	1.00		16	1.00	
Production	121,149	11	1.16	0.50–2.65	9	0.79	0.33–1.80
Maintenance	63,262	4	0.94	0.26–2.70	5	0.86	0.28–2.25
Maintenance[c]	63,262	4	0.87	0.26–2.28	5	0.95	0.32–2.31
Duration							
<1 years	296,901	8	1.00		9	1.00	
1–5 years	113,312	7	0.96	0.31–2.98	7	0.78	0.26–2.31
5–10 years	79,260	8	0.89	0.30–2.85	8	1.18	0.38–3.78
10–20 years	48,527	7	0.51	0.16–1.71	6	0.81	0.22–3.05
>20 years	174	0	—		0	—	

Classifications based on a 10-year lag.
[a]Reference: Korean national population 1988–2001.
[b]Reference: parent plants nos. 1 and 2.
[c]Reference: office and production workers combined.

DISCUSSION

Limitations

The cancer ascertainment for this study population is quite complete because a national cancer registry exists and the rate of migration to other countries is relatively low. Recently, this registry has been estimated to have greater than 95% ascertainment of cancer morbidity status for the Korean people [Korea Central Cancer Registry, 2001b]. During the 1980s through early 1990s, the cancer registry was less complete, possibly capturing 90% or less of cases, but this should not bias study results based on internal comparisons. Because national health insurance has covered all Koreans since 1988, study subjects have no special reasons to have different cancer registration rates compared to the general population.

In occupational cohort mortality studies in the western industrial countries, the healthy worker effect arising largely from employment selection factors is widely acknowledged [McMichael et al., 1974; Fox and Collier, 1976; Vinni and Hakama, 1980; Monson, 1981; Gilbert, 1982; Wen et al., 1983; Blanc et al., 1994; Koskela, 1997]. Although previous studies [Fox and Collier, 1976; Vinni and Hakama, 1980; Monson, 1981; Gilbert, 1982] have shown that cancer has a smaller healthy worker effect than some other diseases such as respiratory or cardiovascular disease, the healthy worker effect for cancer is not absent. This cohort with short follow-up periods and a high proportion of active workers exhibits a large healthy worker effect for cancer [Fox and Collier, 1976; Vinni and Hakama, 1980; Wen et al., 1983; Koskela, 1997]. In this cohort, 91% of the workers were still actively employed at the start of their follow-up which lasted at most 14 years, and thus were highly selected for good health.

Small numbers of cancers for analysis in production and maintenance workers in specific exposure categories was the major limitation of this study, limiting statistical power. The broad grouping of process activities, and combining production and maintenance work within process areas further limited the interpretation of observed associations. The high proportion of workers whose final status was that of office work was a consequence of the structure of this industry

TABLE IV. Cancer Morbidity (SIR, SRR) From Colorectal and Liver Cancer in Korean Iron And Steel Workers

		Colorectal cancer			Liver cancer		
External Comparisons	P-years	N	SIR[a]	95% CI	N	SIR[a]	95% CI
All plants	538,174	56	1.10	0.84–1.42	93	0.83	0.68–1.01
Parent plant No.1	330,863	39	1.07	0.77–1.45	74	0.89	0.70–1.11
Parent plant No.2	97,154	6	1.35	0.54–2.74	6	0.81	0.32–1.64
Office workers	353,763	30	1.18	0.81–1.66	37	0.72	0.51–0.97
Production	121,149	13	0.75	0.41–1.23	36	0.87	0.61–1.18
Maintenance	63,262	13	1.63	0.89–2.68	20	1.09	0.68–1.64
Internal comparisons	P-years	N	SRR	95% CI	n	SRR	95% CI
Parent plant No.1	330,863	39	1.00		74	1.00	
No.1 affiliate	65,702	8	1.14	0.49–2.32	11	0.92	0.46–1.37
Parent plant No.2	97,154	6	1.24	0.45–2.89	6	0.94	0.35–2.09
No.2 affiliate	44,455	3	0.82	0.20–2.32	2	0.37	0.06–1.18
Affiliates versus parents[b]	110,157	11	1.00	0.49–1.88	13	0.75	0.40–1.31
Current job							
Office	353,763	30	1.00		37	1.00	
Production	121,149	13	0.60	0.30–1.15	36	1.22	0.76–1.97
Maintenance	63,262	13	1.24	0.61–2.37	20	1.61	0.91–2.79
Maintenance[c]	63,262	13	1.51	0.77–2.76	20	1.46	0.86–2.36
Duration							
<1 years	296,901	10	1.00		9	1.00	
1–5 years	113,312	21	2.49	1.07–6.37	15	2.04	0.83–5.42
5–10 years	79,260	9	1.03	0.36–3.09	27	4.41	1.81–12.09
10–20 years	48,527	16	2.16	0.78–6.46	42	4.72	1.93–13.21
>20 years	174	0	—		0	—	

Classifications based on a 10-year lag.
[a]Reference: Korean national population 1988–2001.
[b]Reference: parent plants nos. 1 and 2.
[c]Reference: office and production workers combined.

where many management functions were concentrated in the parent company while some production and maintenance support was carried out by subsidiary companies from many of which employment records were not available. Workers could move to the parent company from a subsidiary, a progression that was not common, but their earlier records may not have been available for this study; this would tend to diminish estimated exposure effects and may partly explain the virtually identical cancer morbidity observed for office and production workers. Within the office-work group, there were small numbers of workers with prior production or maintenance work experience who, at the recommendation of the company physician, were assigned office jobs because they couldn't endure heavy work or because an occupational disease such as hearing loss was suspected. (In Korea, workers with suspected occupational diseases typically are moved when recommended under the Korean Occupational Safety and Health Law). Because production work was heavier than office work, the healthy worker survival effect in production workers would be larger than in office workers [Koskela, 1997]. Finally, some process technology is relatively recent at this company, such as in stainless steel production (exposure to Cr^{6+}). For this operation that began in 1989, there was little observation time with 10 years latency, and the single lung cancer case there represented fivefold, non-significant excess.

Concordance With Previous Studies

Previous studies of iron and steel workers [Lloyd, 1971; Redmond et al., 1981; Finkelstein and Wilk, 1990; Finkelstein et al., 1991; Swaen et al., 1991; Moulin et al., 1993; Xu et al., 1996a,b; Bye et al., 1998], and coke oven workers [Chau et al., 1993] have observed significant increase in lung cancer but this study did not identify lung cancer elevations overall. Higher lung cancer morbidity observed in the affiliated plants may in part reflect a higher smoking rate (the smoking rate of parent plant has been at least 15% lower than that of Korean general population) but also more exposure; affiliated plants perform some of the

TABLE V. Cancer Morbidity (SIR, SRR) From Brain, and Lymphohematopoietic Cancer in Korean Iron and Steel Workers

		Brain cancer			Lymphohematopoietic cancer		
External comparisons	P-years	N	SIR[a]	95% CI	N	SIR[a]	95% CI
All plants	538,174	12	1.15	0.61–1.92	36	1.18	0.83–1.60
Parent plant No.1	330,863	11	1.62	0.84–2.77	25	1.25	0.82–1.81
Parent plant No.2	97,154	0	—		3	0.67	0.17–1.73
Office workers	353,763	6	0.98	0.39–1.98	14	0.96	0.54–1.56
Production	121,149	5	1.74	0.62–3.74	14	1.36	0.77–2.20
Maintenance	63,262	1	0.69	0.04–3.02	8	1.40	0.64–2.60
Internal comparisons	P-years	N	SRR	95% CI	N	SRR	95% CI
Parent plant No.1	330,863	11	1.00		25	1.00	
No.1 affiliate	65,702	1	0.52	0.03–2.69	4	0.93	0.27–2.40
Parent plant No.2	97,154	0	—		3	0.60	0.14–1.85
No.2 affiliate	44,455	0	—		4	1.63	0.47–4.39
Affiliates versus parents[b]	110,157	1	0.41	0.02–2.14	8	1.27	0.54–2.69
Current job							
Office	353,763	6	1.00		14	1.00	
Production	121,149	5	1.23	0.34–4.51	14	1.41	0.65–3.10
Maintenance	63,262	1	0.51	0.03–3.21	8	1.53	0.60–3.68
Maintenance[c]	63,262	1	0.46	0.02–2.44	8	1.29	0.55–2.74
Duration							
<1 years	296,901	2	1.00		8	1.00	
1–5 years	113,312	3	2.89	0.32–44.1	12	1.53	0.56–4.48
5–10 years	79,260	5	6.06	0.70–111.	9	1.03	0.33–3.38
10–20 years	48,527	2	2.15	0.15–50.8	5	0.45	0.11–1.78
>20 years	174	0	—		2	4.63	0.48–30.0

Classifications based on a 10-year lag for brain cancer and a 5-year lag for lymphohematopoietic cancer (P-years displayed pertain only to 10-year lag—brain cancer).
[a]Reference: Korean national population 1988–2001.
[b]Reference: parent plants nos. 1 and 2.
[c]Reference: office and production workers combined.

more difficult, hard, and dirty work. For example, in the coke plant, the employees of the parent company worked in the control room, while workers of an affiliated company worked at the coke ovens. The immense changes in smoking behavior since 1965 in the Korean population [Park et al., 2005] may have varied across this steel worker cohort, particularly by levels of employment duration, potentially confounding these analyses. The non-significant excess colorectal cancer incidence in coke oven workers (SRR = 1.4, Table VI) parallels a similar significant excess observed by Chau et al. [1993] (SMR = 3.8).

Maintenance and possibly the Powerhouse areas exhibited excess stomach cancer incidence as well as scattered non-significant excesses at other cancer sites. Observing the highest rates in the low duration stratum for Maintenance and Powerhouse could have occurred if exposures were highest among very short-term employees. Maintenance work probably included metalworking fluid and other oil mist exposures (known to be associated with stomach cancer [Tolbert, 1997]) in addition to plant-wide exposures. Powerhouse work included waste-water treatment with exposures to contaminants from throughout the plants, including mill lubricants, acids, and solvents.

In previous studies, elevation of bladder and kidney cancer has been observed in coke plant workers [Grimsrud et al., 1998; Golka et al., 1999]. In this study, a non-significant excess was observed in the entire cohort and, with small numbers, in three process categories but there were no bladder or kidney cancer cases in the coke plant.

Some studies have investigated lymphohematopoietic cancers [Hurley et al., 1991] and other hematologic abnormalities [Hancock et al., 1984] in coke plant workers exposed to benzene, finding no excesses. Only one aplastic anemia was reported [Hurley et al., 1997]; however, some studies confirmed that leukemia and other lymphohematopoietic cancers were increased in residential areas near coke plants [Westley-Wise et al., 1999; Parodi et al., 2003]. Although not based on coke oven workers, recent studies [Rinsky et al., 2002; Glass et al., 2003; Kang et al., 2005] have shown that benzene exposure levels lower than reported in previous studies were associated with significant increases in lymphohematopoietic cancer. In this study, lymphohema-

TABLE VI. Cancer Morbidity by Working Process in Production and Maintenance Jobs for Korean Iron and Steel Workers

	Material handling, const., QC	Iron production	Coke ovens	Steel, continuous casting	Stainless steel, mini-mill	Cold mill, hot mill: rod, plate	Power-house	Maintenance
All cancer								
n	42	22	14	39	4	66	20	99
SRR[a]	0.81	0.72	0.84	1.22	0.94	0.94	1.23	1.24
95% CI	0.58–1.11	0.46–1.09	0.47–1.37	0.86–1.67	0.29–2.21	0.71–1.23	0.76–1.88	0.98–1.56
Stomach								
n	11	3	5	8	2	14	8	29
SRR	0.90	0.37	1.21	1.02	2.15	0.75	2.06	1.66
95% CI	0.46–1.64	0.09–0.98	0.42–2.68	0.45–1.99	0.35–6.94	0.41–1.30	0.91–4.03	1.05–2.56
Colorectal								
n	7	2	3	3	0	6	1	17
SRR	1.22	0.55	1.41	0.66		0.61	0.46	1.72
95% CI	0.49–2.60	0.09–1.81	0.34–3.86	0.16–1.80		0.23–1.35	0.03–2.11	0.93–3.07
Liver								
n	12	6	3	8	1	20	6	21
SRR	0.91	0.74	0.75	1.08	0.89	1.24	1.51	1.04
95% CI	0.47–1.63	0.29–1.57	0.18–2.01	0.48–2.11	0.05–4.04	0.72–2.03	0.58–3.21	0.62–1.68
Lung								
n	0	2	1	4	1	2	1	5
SRR		1.23	1.01	2.30	5.54	0.46	0.90	1.04
95% CI		0.20–4.21	0.06–4.85	0.66–6.22	0.30–27.83	0.07–1.61	0.05–4.32	0.34–2.63
Bladder/kidney								
n	1	2	0	4	0	3	2	6
SRR	0.34	1.39		1.92		0.65	2.50	0.98
95% CI	0.02–1.67	0.22–4.80		0.56–5.08		0.15–1.94	0.39–8.74	0.36–2.35
Brain								
n	1	1	0	1	0	3	0	1
SRR	0.73	1.24		1.11		1.96		0.32
95% CI	0.04–4.08	0.07–6.90		0.06–5.93		0.42–7.06		0.02–1.72
Lymphohematopoietic								
n	4	0	4	4	0	9	1	6
SRR	1.27		3.46	1.54		2.00	0.88	0.74
95% CI	0.36–3.40		1.02–8.91	0.45–3.95		0.86–4.29	0.05–4.16	0.28–1.70

[a]By Poisson regression with single exposure term (ever-exposed) for each model; stratified on age, calendar time, and employment duration. Exposure classification for cancer outcomes based on 10-year lag (5 year for leukemia). Baseline reference: all observation time of workers with no prior duration as production or maintenance in process area being analyzed.

topoietic cancer was slightly higher in the entire cohort, and somewhat but not significantly elevated in production and maintenance workers, compared to the Korean general population. The coke plant was the only operation showing a significant excess, suggesting benzene exposures which, in recent years, have ranged as high as 1 ppm (8 hr TWA) but were higher prior to 1990. There was just one air-sampling report for workers' benzene exposure levels of this coke oven before 1990. In 1990, the mean benzene exposure level was 0.19 to 2.06 ppm by working process. The lowest mean exposure was observed for guide-car operators (mean 0.19 ppm, 0.12–0.23 ppm) and the highest exposure was observed for by-product coking oven workers (mean 2.06 ppm, 0.23–6.87 ppm) [School of Public Health, Seoul National University, 1990]. Three of the four cases in the coke plant were acute myelocytic leukemia, consistent with a benzene etiology; and the fourth was a diffuse lymphoma (International Classification of Diseases for Oncology, 3rd edition). This finding is supported by chromosomal aberration studies [Holeckova et al., 2004; Kim et al., 2004a,b] of workers exposed to low-level benzene, indicating that benzene is genotoxic and suggesting that chromosomal aberrations may

TABLE VII. Stomach Cancer Incidence by Duration in Maintenance, Power House, or Stainless Steel Activities in Korean Iron and Steel Workers

Process duration	No. of deaths	SRR[a]	95% CI
Maintenance			
(0–1 year)	7	3.65	1.38–8.52
(1–5 years)	9	1.57	0.67–3.34
(5–10 years)	8	1.56	0.64–3.42
(10–35 years)	5	1.48	0.49–3.71
Power house			
(0–1 year)	3	5.95	1.40–17.37
(1–5 years)	1	0.93	0.52–4.37
(5–10 years)	2	2.00	0.32–6.69
(10–35 years)	2	2.15	0.34–7.35
Stainless steel production			
(0–1 year)	1	6.24	0.34–32.17
(1–5 years)	0	0.00	—
(5–10 years)	0	0.00	—
(10–35 years)	1	13.65	0.76–66.26

[a]By Poisson regression with single log-linear model, adjusted for age and calendar time (internal, direct standardization), and employment duration; with additional term indicating whether observation time was classified as having prior duration in any of the eight process areas as production or maintenance worker.

play a role in benzene-induced carcinogenesis. The recent work of Kim et al. [2004a], who studied a group of coke oven workers included in the present cohort, has shown that low-level workplace benzene exposures (0.01–0.74 ppm) are associated with significant increases in both monosomy and trisomy of chromosome 8 and 21.

CONCLUSION

This study describes the cancer morbidity experience of a modern Korean industrial workforce 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 cancer incidence. The study reveals some work-related excess cancer morbidity in the modern iron and steel industry of Korea but the interpretation of these findings is hampered by the small numbers of cases and the limited exposure history available for individual workers. Excess lymphohematopoietic cancer was observed in coke oven workers, and may reflect higher exposures prior to 1990. In the future, the presence or absence of work-related excesses will become clearer, particularly for the recent stainless steel operations.

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