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Mortality of Iron and Steel Workers in Korea

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Background *The mortality experience of iron and steel workers from modern plants in developing countries has not been extensively described.*
Methods *Mortality at two Korean iron and steel manufacturing complexes was analyzed using Poisson regression methods with both direct and indirect standardization. Work histories were linked with a national mortality registry. Workers (44,974) hired beginning in 1968 were followed from 1992 to 2001.*
Results *The 806 deaths observed during 10 years of follow-up comprised 2% of the population at risk and represented a large healthy worker effect (HWE) for all causes (SMR = 0.59, 95% CI = 0.55–0.63) and for cancer (SMR = 0.79, 95% CI = 0.70–0.90). Mortality at subsidiaries was considerably higher than at the parent plants (SRR = 1.71, 95% CI = 1.47–1.99). Relative mortality rates declined with employment duration: >20 years had significantly reduced mortality (SRR = 0.59, 95% CI = 0.43–0.82) compared to duration <1 year (test for trend: P = 0.0006). Fatal injury deaths in the first year were highly elevated (SMR = 3.10, 95% CI = 2.17–4.26) declining to less than that expected after 5 years. Cancer mortality was elevated in stainless steel production (SRR = 3.26, 95% CI = 1.37–6.49) and overall mortality was elevated for work in plant maintenance departments (SRR = 1.17, 95% CI = 1.00–1.37), particularly for fatal injuries (SRR = 1.67, 95% CI = 1.29–2.14). All-cause mortality increased with employment duration in the steel-production departments, as did fatal injuries in material handling/ construction.*
Conclusions *This steelworker cohort exhibits excess mortality in some process areas. More detailed retrospective exposure assessment and future follow-up of this cohort will better define health risks in the modern iron and steel manufacturing.* Am. J. Ind. Med. 48:194–204, 2005. *© 2005 Wiley-Liss, Inc.*

KEY WORDS: developing country; iron and steel industry; retrospective cohort study; mortality; healthy worker effect; stainless steel; fatal work injury

INTRODUCTION

Workers in the iron and steel industry are exposed to toxic metals (chromium, manganese, lead, and cadmium etc.), carbon monoxide, various dusts, fumes, acid mists, solvents, oil mists, and physical hazards such as heat, noise, and ionizing radiation. Previous studies of steel workers observed increased rates of cancer and other diseases [Lloyd, 1971; Redmond et al., 1981; Finkelstein and Wilk, 1990; Finkelstein et al., 1991; Swaen et al., 1991; Chau et al., 1993; Moulin et al., 1993; Xu et al., 1996a,b; Wu et al., 1997a,b;

Abbreviations: SMR, standardized mortality ratio; SRR, standardized rate ratio; 95% CI, 95% confidence interval; KNSO, Korean National Statistical Office.

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Bye et al., 1998]. A mortality survey of 21,800 Brazilian steel workers observed lower than expected overall mortality (SMR = 0.48) but more than expected deaths from unintentional injury (SMR = 1.50, 95% confidence interval (CI) = 1.30–1.72) accounting for half of all deaths [Barreto et al., 1996].

Workers at a large Korean iron and steel-making company, established in 1968 with relatively modern facilities, likely have been exposed to lower levels of many hazardous agents than were present in previous studies, often at companies established in the early 1900s or before. This investigation evaluated exposure-mortality associations at this company and described mortality patterns in relation to the Korean reference population in which the three leading cancers in 1999 in men were stomach, liver, and lung (and bronchus) [Central Cancer Registry Center, 2003]; in US, the three leading cancers were prostate, lung, and colo-rectal [National Cancer Institute, 2002].

MATERIALS AND METHODS

Cohort Definition and Data Collection

The workers were employed in two large iron and steel plants at different locations, or in 28 nearby affiliated or subsidiary plants producing coke or providing maintenance support. The parent plants had similar industrial processes (except for stainless steel) and were established in 1968 (Parent Plant No. 1) and 1982 (Parent Plant No. 2). The affiliated plants were established 1977–1997. This company has numerous additional subsidiaries involved in housing, food preparation, and cleaning, but work histories were not available for these. The cohort was all male Korean workers employed any time during 1 January 1968–31 December 2001 and who were alive on 1 January 1992. Female workers were not included because they comprised 4% of the workforce, mostly in office jobs, and were relatively young. Follow-up was from date of hire or 1 January 1992, whichever was later, until the earlier of date of death or 31 December 2001. The company provided the name, residence registration number (RRN, a unique 13-digit number assigned to all Koreans), birth date, dates of hiring and ending employment, and individual job histories for each worker. The history specified successive department and job assignments.

Deaths were identified by the Korean National Statistical Office (KNSO). This registry estimates that it has greater than 95% registration of deaths; cause of death was available beginning in 1992. KNSO records provide the RRN, cause of death (International Classification of Diseases, 10th Edition), and date of death. Study subjects were matched to the KNSO database using the RRN (in which date of birth is embedded). Reference mortality rates for the Korean population was derived from KNSO data for 1994–2001.

The population at risk at the start of follow-up (1992) was not well specified: a worker leaving employment and dying before 1992 would not generally be known to have died. For these reasons, a worker was specified to be alive as of 31 December 1991 provided any of the following conditions were met: the date of employment termination was after 1 January 1992; the date of death was known to be after 1 January 1992; or, the worker had a medical insurance claim originating any time after 1 January 1992. Koreans have universal health care and an insurance-claims database was available beginning in 1998. Of the more than 37 thousand workers still employed after 1991 and surviving to 2002, only 9 had no medical insurance claim. Workers terminating before 1 January 1992 without a medical claim during 1998–2001 and not known to have died after 1991 were presumed deceased prior to 1992 and excluded.

Workers active in 1994 or later and employed in the parent plants were asked by the company for smoking information. Smoking histories were obtained for 18,915 of 20,209 workers active in 1994 and compared with those of the Korean male population available from a national survey.

Exposure Assessment

The production and maintenance departments were classified into eight process areas: material handling, construction, and quality control (product inspection); iron production (ore preparation, sintering, blast furnace using iron ore and coke); coke plants (including byproducts); steel production (oxygen converter, continuous casting, and rolling); stainless steel production (since 1989 and only at Parent Plant 1); cold mill and hot mill; powerhouse; and maintenance and repair (including central and plant-based departments). In most departments, workers could have worked in production, maintenance, or office jobs. At each interval of follow-up, a worker's cumulative duration of employment while a production or maintenance worker was calculated in each process category.

Personal breathing zone air concentrations based on sampling for at least 6 hr were available in process areas at one of the two iron and steel complexes during 1994–2000 (Table I). Probably representing worst case situations, these air samples indicate that exposures for some of the materials of concern (CO, Cr) were quite low while for others (benzene, H_2SO_4, heat stress, Mn, HCl, CTPV, PAHs) exposures approached or exceeded Korean threshold limit values (TLV) [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 worker demands following investigations prior to 1990 led to improvements in engineering controls.

TABLE I. Concentration of Air Contaminants by Process Area at One Iron and Steel Complex of the Company During 1994–2000; Korea

Material threshold limit value (TLV[a])	Process area	Range of sample-means in process areas[b]
Benzene (ppm; TLV = 1.0)	Coke plant	**ND-0.938**[c]
	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)	ND-0.05
Hexavalent chromium (mg/m^3; TLV = 0.05)	Cold rolling mill	ND-0.008
	Stainless steel mill	ND-0.004
Chromium fume (mg/m^3; TLV = na)	Maintenance (central)	ND-0.023
	Stainless steel mill	ND-0.020
Chromium(metal) (mg/m^3; TLV = 0.50)	Maintenance (central)	ND-0.197
	Stainless steel mill	ND-0.044
	Quality test	ND-0.020
	Cold rolling mill	ND-0.012
	Stainless steel (maintenance)	ND-0.010
	Steel production	ND-0.006
CTPV (mg/m^3; TLV = 0.20)	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 (μg/m^3; TLV = 200)	Coke plant	15.5–96.4 (K)
H_2S (ppm; TLV = 10)	Iron production (blast furnace)	ND-2.783
H_2SO_4 (ppm; TLV = 1)	Cold rolling mill	**ND-1.578**
	Stainless steel mill	ND-0.350
	Stainless steel (maintenance)	ND-0.589
HCl (ppm; TLV = 5)	Cold rolling mill	**ND-4.5**
	Cold rolling mill (maintenance)	**ND-4.5**
	Quality testing (chemical analysis)	ND-0.417
	Powerhouse (waste water)	ND-0.340
Heat stress (WGBT; TLV =) 30, light work; 26.7, moderate work; 25.0, heavy work	Iron production (blast furnace)	**31.2–32.1**
	Steel production	**27.5–29.3**
	Steel production (cont. casting)	**27.7–29.2**
HF (ppm; TLV = 3)	Stainless steel mill	ND-0.857
	Stainless steel (maintenance)	ND-0.843
Mn(dust) (mg/m^3; TLV = 5.0)	Quality test	0.826
	Maintenance (central)	ND-0.417
	Steel production	ND-0.155
	Stainless steel mill	ND-0.031
Mn(fume) (mg/m^3; TLV = 1.0)	Maintenance (central)	ND-0.531
	Steel production	ND-0.146
	Stainless steel mill	ND-0.015
NH_3 (ppm; TLV = 25)	Stainless steel mill	ND-0.950
	Stainless steel (maintenance)	ND-0.890
Ni(metal) (mg/m^3; TLV = 1.0)	Maintenance (central)	ND-0.201
	Stainless steel mill	ND-0.033
	Quality testing	ND-0.020
	Steel production	ND-0.007
SO_2 (ppm; TLV = 2)	Blast furnace	ND-1.600
Welding fume (mg/m^3; TLV = na)	Maintenance (central)	0.215–7.175

TABLE I. (*Continued*)

Material threshold limit value (TLV[a])	Process area	Range of sample-means in process areas[b]
CO (ppm; TLV = 50)	Iron production (blast furnace)	4.50–39.20
	Powerhouse	ND-19.00
	Iron production (furnace maintenance)	ND-10.58
	Cold rolling mill	3.00–13.50
	Hot rolling mill	1.05–8.667
	Coke plant	6.00–7.625
	Stainless steel mill	2.50–5.500
	Steel production	4.50–5.100

ND, non-detectable; CTPV, coaltar pitch volatiles; PAH, polycyclic aromatic hydrocarbon; WGBT, wet bulb globe temperature index.
[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 based on personal samplers with 6 or more hours sampling time except for CO; CO was measured by spot measurement with detector tubes. Samples taken by employer except for (K): by Korean Occupational Safety and Health Administration. ND = below limit of detection.
[c]Upper range approaches or exceeds Korean TLV: in bold font.

Classification for and Specification of Poisson Regression Models

A classification table for Poisson regression analysis of mortality was calculated using a FORTRAN program developed previously [Park et al., 2002]. 414,259 person-years of observation were jointly classified in 10 age group (<20, 20–24, 25–29, 30–34,. . ., 65+), 2 calendar (1992–96, 1997–01), 4 plant (Parent Plant 1, Parent Plant 2, subsidiaries to plant 1, subsidiaries to plant 2), 3 job (office, production, or maintenance), and 5 employment duration (0–1, 1–4.99, 5–9.99, 10–19.99, 20+ years) categories, together with 5 levels of cumulative duration in each of the 8 process categories (0, 1–1.99, 2–4.99, 5–9.99, 10+ years). The unit of follow-up was 10 days. The plant classifying category was defined as *plant where first hired*, to address possible differential selection on health status at hire. The job-classifying category was *current job*, or *most recent* if no longer employed and, following an initial orientation period, did not change for almost all workers. Maintenance jobs included both skilled and unskilled workers. For cancer outcomes the classification was based on a 10-year lag (5 years for leukemia). For analyses of fatal injury, follow-up was terminated 1 year past the end of employment, to allow for delayed death following a workplace injury; process exposure was based on current or most recent department.

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:

$$\text{rate} = \exp(\hat{a}_0 + \hat{a}_1 X_1 + \hat{a}_2 X_2 + \ldots)$$

where, $\hat{a}_0$ (intercept), $\hat{a}, \hat{a}_1, \hat{a}_2, \ldots$ are parameters to be estimated.

Poisson regression models were fit using EPICURE software [Preston et al., 1993]. Models with the largest decrease in deviance (i.e., decrease in −2log(likelihood) with addition of exposure terms were considered ''best'' fitting. In some models, external standardization on age and calendar time was accomplished using Korean mortality rates (in 5-year intervals) as a multiplier of person-years which yields models of standardized mortality ratios (SMRs) in which the intercept is an estimate of the (log) standardized mortality ratio for workers without the specified exposures. This method permits internal comparisons on exposures, however, bias can arise from age-exposure interactions. In other models, direct standardization was achieved by ''stratification,'' a procedure in EPICURE in which categorical classifying variables such as age, year, and duration (and all interactions) are included in the model. Directly standardized rate ratios (SRRs) allowed unbiased comparisons across exposure and other descriptive variables. Employment duration was included as a stratifying variable in order to account for the declining relative mortality of the study population with duration.

RESULTS

Demographics of Mortality Cohort

Of 46,762 workers identified, 0.6% (n = 299) were ineligible because they were hired after 2001, were known to have died before 1992, or had inconsistent information (e.g., date of death earlier than date of hire). Workers not known to be alive on 1 January 1992 comprised 3.2% (n = 1,489) and were excluded, leaving a study population of 44,974 which was followed for a total of 414,259 person-years (Table II). Excluded workers came predominately from the older parent plant (n = 1,244, 83%). Half of the study population

TABLE II. Mortality From all Causes in Korean Iron and Steel Workers

	Person-years	Deaths	SMR[a]	95% CI	SRR	95% CI
All plants	414,259	806	0.59	0.55–0.63	—	
By first plant						
Parent Plant, no. 1	243,141	459	0.49	0.45–0.53	1.00	—
No. 1-affilliated	51,806	149	0.85	0.72–0.99	1.71	1.41–2.05
Parent Plant no. 2	80,843	101	0.64	0.52–0.77	1.13	0.89–1.43
No. 2-affilliated	38,469	97	0.95	0.78–1.15	1.83	1.45–2.28
Affiliated versus parent					1.71	1.47–1.99
By current job class						
Office workers	158,598	302	0.55	0.49–0.61	1.00	—
Production	154,043	311	0.57	0.51–0.64	1.05	0.89–1.23
Maintenance	101,618	193	0.68	0.59–0.78	1.22	1.01–1.47
Maintenance versus other					1.19	1.01–1.40
By duration employed						
<1 year	39,112	75	0.90	0.71–1.11	1.00	—
1–5 years	100,876	181	0.71	0.61–0.82	0.83	0.63–1.09
5–10 years	118,978	180	0.58	0.50–0.67	0.72	0.55–0.95
10–20 years	123,091	255	0.52	0.46–0.58	0.68	0.52–0.90
>20 years	32,203	115	0.49	0.41–0.59	0.59	0.43–0.82

[a]Reference: Korean national population 1994–2001.

(n = 22,790) was still employed at the end of 2001. Workers whose last job was in an office (n = 16,565) contributed the most observation time (158,598 person-years) followed by production (n = 16,771, 154,043 person-years) and maintenance (n = 11,638, 101,618 person-years) (Table II).

Smoking Characteristics

Surveys at the parent plants revealed that 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. The non-response rate was less than 10% in all surveys. The current smoking rate was similar across categories of last job. The overall smoking rate of study subjects in 1994 was about 15% lower than that of Korean male population in that year in the same age range (20–69) [Jee, 1999]. Although not age-adjusted, these smoking rates were based on the active work force, which would limit the age range and tend to be similar across plants.

Mortality by Plant and Job Class

There were 806 deaths or 1.8% of the study population during 1992–2001 which was low as compared to the Korean general population (SMR = 806/1,377 = 0.59, 95% CI = 0.55–0.63). Only five deaths were attributed to respiratory diseases other than cancer. Mortality was higher at Plant 2, and at the affiliated plants (SRR = 1.71, 95% CI = 1.47–1.99) (Table II). Office and production workers had almost identical overall mortality in comparison to which maintenance worker mortality was significantly elevated (SRR = 1.19, 95% CI = 1.01–1.40) (Table II). Cancer mortality at the affiliated plants was higher, than in the parent plants (SRR = 1.56, 95% CI = 1.16–2.08) and was also elevated for maintenance workers compared to office and production workers (SRR = 1.33, 95% CI = 0.95–1.82) (Table III).

Injury deaths were two to three times higher in the affiliated plants compared to the parent plants (Table IV). Non-cancer liver disease mortality (48 deaths) was much less than expected (SMR = 0.27, 95% CI = 0.20–0.36) but was almost double in affiliated plants versus parent plants SRR = 1.88, 95% CI = 0.97–3.42) (Table V). Lung cancer mortality (31 deaths) was less than expected overall (SMR = 0. 81, 95% CI = 0.56–1.26) (Table V) but differed between Parent Plant 1 (SMR = 0.58, 95% CI = 0.35–0.90) and its affiliated plants (SMR = 1.91, 95% CI = 0.96–3.35, data not shown); lung cancer mortality in affiliated plants was more than double that of parent plants (SRR = 2.14, 95% CI = 0.98–4.43) (Table V).

Mortality by Employment Duration

All-cause mortality declined with duration of employment, from SMR = 0.90 at less than 1 year to SMR = 0.49 at greater than 20 years (Table II), a significant reduction (SRR = 0.59, 95% CI = 0.43–0.82, data not shown). A test

TABLE III. Mortality From all Cancer in Korean Iron and Steel Workers

	Person-years	Deaths	SMR[a]	95% CI	SRR	95% CI
All plants	414,259	231	0.79	0.70–0.90	—	—
By first plant[b]						
Parent Plant, no. 1	243,141	148	0.70	0.59–0.82	1.00	—
No. 1-affilliated	51,806	42	1.11	0.81–1.48	1.58	1.10–2.20
Parent Plant no. 2	80,843	19	0.86	0.53–1.31	1.30	0.76–2.10
No. 2-affilliated	38,469	22	1.11	0.71–1.64	1.67	1.03–2.57
Affiliated versus parent					1.56	1.16–2.08
By current job class[b]						
Office workers	260,823	100	0.70	0.57–0.86	1.00	—
Production	97,893	84	0.82	0.66–1.01	1.14	0.85–1.54
Maintenance	55,399	47	1.02	0.76–1.34	1.41	0.98–2.00
Maintenance versus other					1.33	0.95–1.82
By duration employed[b]						
<1 year	209,535	45	0.72	0.52–0.95	1.00	—
1–5 years	88,279	54	0.94	0.71–1.21	1.25	0.82–1.95
5–10 years	67,975	57	0.83	0.63–1.06	1.17	0.75–1.84
10–20 years	48,152	74	0.73	0.58–0.91	1.05	0.68–1.66
>20 years	174	1	1.04	0.06–4.58	1.35	0.07–6.54

[a]Reference: Korean national population 1994–2001.
[b]Calculated with a 10-year lag.

TABLE IV. Mortality From Fatal Injuries in Korean Iron And Steel Workers

	Person-years[a]	Deaths	SMR[b]	95% CI	SRR	95% CI
All plants	264,680	278	0.96	0.85–1.07	—	
By first plant						
Parent Plant, no. 1	153,652	107	0.61	0.50–0.74	1.00	—
No. 1-affiliated	29,593	66	1.98	1.54–2.50	3.08	2.25–4.18
Parent Plant no. 2	58,362	56	0.96	0.73–1.24	1.22	0.86–1.71
No. 2-affiliated	23,050	49	2.04	1.52–2.66	2.77	1.94–3.91
Affiliated versus parent					2.76	2.16–3.52
By current job class						
Office workers	94,421	104	0.99	0.81–1.20	1.00	—
Production	107,391	85	0.72	0.57–0.88	0.70	0.52–0.93
Maintenance	62,845	89	1.33	1.07–1.63	1.26	0.95–1.68
Maintenance versus other					1.51	1.17–1.94
By duration employed						
<1 year	11,183	34	3.10	2.17–4.26	2.87	1.69–4.79
1–5 years	46,209	75	1.59	1.25–1.97	1.56	1.00–2.43
5–10 years	84,584	67	0.78	0.60–0.98	1.00	0.67–1.47
10–20 years[c]	98,502	77	0.68	0.54–0.85	1.00	—
>20 years	24,201	25	0.75	0.50–1.09	1.04	0.60–1.78

[a]Follow-up terminated 1 year past employment termination to capture work-related injury.
[b]Reference: Korean national population 1994–2001.
[c]Reference level.

TABLE V. Cause-Specific Mortality for all Korean Iron and Steel Workers and Comparing Affiliated Plants With Parent Plants

		All plants		Affiliated versus parent	
	Total deaths	SMR[a]	95% CI	SRR[b]	95% CI
Ischemic heart disease	31	0.71	0.48–0.98	1.07	0.39–2.46
Stroke	49	0.52	0.39–0.68	1.43	0.73–2.66
Liver disease	48	0.27	0.20–0.36	1.88	0.97–3.42
Stomach cancer[c]	42	0.69	0.51–0.93	1.43	0.68–2.77
Liver cancer	81	0.82	0.66–1.02	1.06	0.59–1.79
Lung cancer	31	0.81	0.56–1.26	2.14	0.98–4.43
Leukemia	16	1.45	0.85–2.28	1.37	0.38–3.97

[a]Reference: Korean national population 1994–2001.
[b]Reference: Parent Plants 1, 2.
[c]Cancer outcomes based on 10-year lag (5 year for leukemia).

for trend (duration categories represented as 0,1,2,3,4) was highly significant (for each duration increment, SRR = 0.88, 95% CI = 0.83,0.95, $P = 0.0006$, data not shown). For cancer deaths, there was no consistent trend on employment duration with a 10-year lag (Table III) or without a lag (SMR = 0.66, 0.61, 0.84, 0.87, 0.79, respectively; data not shown).

Injury deaths were highly elevated in the <1 year duration category (SMR = 3.10, 95% CI = 2.17–4.26) (Table IV) which, compared to duration >5 year, were highly significantly elevated (SRR = 2.87, 95% CI = 1.69–4.79). The trend on duration for all deaths other than injury was moderated, declining from SMR = 0.56 at <1 year to SMR = 0.44 at > 20 years (data not shown). For non-cancer liver disease, mortality declined even more sharply with duration than did all-cause mortality, from SMR = 0.51 at less than 1 year to SMR = 0.24 at greater than 20 years (data not shown).

Mortality by Process Area

All-cause mortality, evaluated for each process category individually, was elevated for workers ever in maintenance (SRR = 1.17, 95% CI = 1.00–1.37) and possibly for those ever in steel production (SRR = 1.14, 95% CI = 0.90–1.43) (Table VI). In maintenance, fatal injuries and cancer accounted for most of the excesses. In steel production non-significant excesses were observed for stroke, heart disease, liver disease, and liver cancer. Non-significant heart disease excess mortality was also observed in the hot/cold mill, powerhouse, and stainless steel categories. All-cancer mortality was significantly elevated in stainless steel (SRR = 3.26, 95% CI = 1.37–6.49) based on seven deaths from stomach, liver, and lung cancer (Table VI). Other process areas had elevations for specific disease groups but numbers of deaths were small. Fatal injury showed deficits for all except maintenance (SRR = 1.67, 95% CI = 1.29–2.14) and material handling/construction. (SRR = 1.43, 95% CI = 0.81–2.34) (Table VI).

Poisson regression with categorical duration terms showed a consistent trend in all-cause mortality by duration in steel production (Table VII, Model 1). The test for trend was significant (for each duration increment, SRR = 1.09, 95% CI = 1.01,1.17, $P = 0.027$, data not shown). For duration in maintenance, a mixed picture was observed for all-cause mortality (Table VII, Model 1). The baseline reference in this model was observation time as production or maintenance with no prior duration in steel production or maintenance. Liver disease mortality, which exhibited an excess in affiliated plants and among those ever in iron or steel production, showed excess mortality in all duration levels of iron production and steel production but no trends were discernable (data not shown). Fatal injury relative rates were increased by about 65% for workers whose current department was material handling or maintenance, when compared to the rest of the study population. Restricting comparisons to workers assigned to other defined process areas demonstrated a doubling of injury fatality rates in material handling/construction. (SRR = 2.06, 95% CI = 1.12–3.53) and maintenance (SRR = 2.05, 95% CI = 1.49–2.84) (Table VII, Model 2a). Risk increased with cumulative duration in material handling (Table VII, Model 2b), in contrast to the downward trend observed for injuries on overall employment duration (Table IV). In maintenance fatal injuries were significantly elevated for all durations but highest in the <1 year (SRR = 2.31, 95% CI = 1.25–4.19) and >10 year (SRR = 2.44, 95% CI = 1.52–3.83) categories.

DISCUSSION

Limitations

Quite complete mortality ascertainment was made possible by the low rate of migration of Koreans to other

TABLE VI. Mortality by Process Area in Production and Maintenance Jobs for Korean Iron and Steel Workers

	Material handling, construction, QC	Iron production	Coke plant	Steel production	Stainless steel	Cold mill, hot mill-rod, plate	Power-house	Maintenance
All causes								
n[a]	92	62	35	79	16	115	23	218
SRR[b]	1.04	0.91	0.85	1.14	0.81	0.90	0.87	1.17
95% CI	0.83–1.30	0.69–1.17	0.59–1.17	0.90–1.43	0.47–1.29	0.73–1.10	0.55–1.28	1.00–1.37
All cancer								
n	24	12	4	19	7	35	8	50
SRR	0.84	0.77	0.44	1.11	3.26	0.99	0.93	1.19
95% CI	0.53–1.27	0.40–1.32	0.14–1.04	0.66–1.73	1.37–6.49	0.67–1.43	0.42–1.78	0.85–1.63
Heart disease								
n	3	3	2	3	1	8	2	5
SRR	0.69	0.87	1.06	1.24	1.52	1.86	1.65	0.74
95% CI	0.16–1.99	0.21–2.53	0.17–3.58	0.29–3.55	0.08–7.35	0.76–4.18	0.26–5.59	0.25–1.82
Stroke								
n	6	5	3	7	0	6	1	11
SRR	0.94	1.10	1.08	1.96		0.86	0.62	1.13
95% CI	0.35–2.09	0.37–2.59	0.26–2.99	0.80–4.16		0.32–1.93	0.03–2.86	0.54–2.19
Liver non-cancer								
n	6	8	3	7	0	9	2	8
SRR	0.90	1.91	1.16	2.06		1.46	1.30	0.66
95% CI	0.34–2.00	0.82–3.94	0.28–3.19	0.84–4.35		0.64–2.97	0.21–4.29	0.28–1.35
Stomach Cancer								
n	7	1	0	1	2	6	3	11
SRR	1.67	0.35		0.32	5.96	0.92	2.12	1.61
95% CI	0.66–3.72	0.02–1.64		0.02–1.49	0.94–20.7	0.34–2.13	0.50–6.06	0.75–3.25
Liver Cancer								
n	12	8	2	10	3	11	2	16
SRR	0.98	1.28	0.57	1.62	3.42	0.74	0.55	0.94
95% CI	0.50–1.76	0.56–2.52	0.09–1.83	0.78–3.01	0.83–9.39	0.37–1.37	0.09–1.74	0.52–1.59
Lung Cancer								
n	0	0	1	3	1	4	1	6
SRR			0.94	1.41	5.88	0.99	0.83	1.30
95% CI			0.05–4.49	0.33–4.11	0.33–28.9	0.29–2.67	0.05–3.96	0.47–3.09
Leukemia								
n	1	0	1	1	0	3	2	5
SRR	0.96		1.56	0.66		1.28	5.18	1.32
95% CI	0.05–5.04		0.09–7.78	0.04–3.31		0.29–4.07	0.80–19.2	0.41–3.70
Fatal injury								
n	15	15	8	20	4	19	3	89
SRR	1.43	0.82	0.67	0.93	0.44	0.44	0.71	1.67
95% CI	0.81–2.34	0.47–1.34	0.31–1.27	0.57–1.43	0.13–1.02	0.27–0.69	0.18–1.87	1.29–2.14

QC, Quality control.
[a]n, Number of deaths.
[b]By Poisson regression with single exposure term in each model (ever-exposed, except for injury: current or last assignment); stratified on age and calendar time (internal, direct standardization), 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.

TABLE VII. Models for All-Cause and Injury Mortality by Duration in Process Area

		No. of deaths	SRR[a]	96% CI
1. All-cause mortality				
(Duration in)	Steel production (0–1 year)	3	0.39	0.10–1.02
	(1–5 years)	17	1.01	0.60–1.60
	(5–10 years)	21	1.22	0.76–1.86
	(10–35 years)	38	1.57	1.09–2.18
	Maintenance (0–1 year)	36	1.37	0.93–1.98
	(1–5 years)	56	1.09	0.80–1.46
	(5–10 years)	45	0.94	0.67–1.31
	(10–35 years)	81	1.41	1.09–1.81
	(model $X^2 = 18.50$ (8 df), $P = 0.017$)			
2. Injury mortality with any-process indicator term[b]				
(a) Ever in	Material handling, construction, QC	15	2.06	1.12–3.53
	Maintenance	89	2.05	1.49–2.84
	(model $X^2 = 21.16$ (2 df), $P < 0.0001$)			
(b) Duration in	Material handling, construction (0–1 year)	2	0.75	0.12–2.49
	(1–5 years)	3	0.78	0.19–2.13
	(5–10 years)	5	1.61	0.55–3.74
	(10–35 years)	11	3.01	1.46–5.67
	Maintenance (0–1 year)	21	2.31	1.25–4.19
	(1–5 years)	27	1.65	1.01–2.63
	(5–10 years)	24	1.75	1.03–2.86
	(10–35 years)	29	2.44	1.52–3.83
	(model $X^2 = 29.37$ (8 df), $P = 0.0003$)			

[a]By Poisson regression with single log-linear model, adjusted for age and calendar time (internal, direct standardization), and employment duration.
[b]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.

countries. Foreign workers, usually with specialized skills, did not have RRNs and were excluded from this study. The small numbers of deaths in specific categories reflected the young age of the cohort and small number of years of follow-up. Excluding deaths prior to 1992 should not bias exposure associations but did reduce statistical power. The broad process categories and combined production and maintenance work within them further limited the interpretation of associations. Finally, some process technology is relatively recent at this company, such as in stainless steel production, which began in 1989.

Time trends in health status in Korea are complicated by the history of smoking, itself relatively recent, and rapidly changing. Smoking began in Korea on a large scale among men after 1965 but has declined since 1990 with public health efforts. In Parent Plant 1, an aggressive health promotion campaign preceded the large drop in smoking from 1994 to 2000. Higher mortality observed in the affiliated plants may in part reflect a higher smoking rate but also socioeconomic differences as reflected in their lower wages [Korean Ministry of Labor, 2002]. Smoking differences could not be investigated. Non-cancer liver disease, which had low overall mortality, arises in Korea largely from maternally transmitted hepatitis B infection and is declining rapidly with public health measures.

Healthy Worker Effect (HWE)

The healthy worker effect (HWE) arising largely from employment selection factors is widely acknowledged [McMichael et al., 1974; Fox and Collier, 1976; Monson, 1981; Arrighi and Hertz-Picciotto, 1994] and commonly results in all-cause SMRs of 0.70–0.85 for Caucasian men in the absence of workplace hazards [Park et al., 1991]. Cancer SMRs typically are in the range 0.80–0.90 [Park et al., 1991]. In US, African-American men working in modern industry typically have a stronger HWE representing additional selection in relation to the US African-American population [Park et al., 1994; Delzell et al., 2003]. In newly industrialized countries, such as Korea, a different worker selection environment may arise from rural to urban migration concurrent with growth of modern technological manufacturing and improving incomes and health care. The strong HWE observed in the iron and steel workers here (all-cause SMR = 0.59, 95% CI = 0.55–0.63) and in Brazilian steel workers (all-cause SMR = 0.48, 95%

CI = 0.43–0.53) [Barreto et al., 1996] supports this conjecture.

This study suggests that social class differences observed in Western countries (e.g., white collar vs. blue collar) may be less pronounced in Korea where all-cause mortality was virtually identical between those whose job classification was office work versus those in production. On the other hand, deficits for many outcomes across process areas in this cohort (Table VI) and the improvement in the model of injury mortality by restricting the comparison to other process areas (Table VII) suggests that the ''unexposed'' office group may include workers with previous or current exposures not identified in the available work history. For Brazilian steel workers, in contrast, the difference in overall mortality of production/maintenance versus white collar workers was quite large—almost twofold [Barreto et al., 1996]; for fatal injuries the difference was threefold.

The decline in SMRs or SRRs with employment duration seen for several outcomes, such as *all causes excluding injury*, or liver disease, appears also to be a manifestation of healthy worker and worker survivor effects and indicates that, if not controlled for, bias could result in analyses of associations between cumulative exposure (or exposure durations) and health outcomes. An attenuating positive association between duration of exposure and mortality has been noted in many studies in the US [Stayner et al., 2003].

Exposure Effects

While observing increasing risk with process duration supports causal inference, as seen for all-cause mortality in steel production, the absence of such a trend in processes encompassing diverse exposures and mixed duration-career paths, is not strong evidence against it. In steel production, overall mortality compared to several other production areas, appears to be elevated by about 27% (SMR = 1.14 vs. 0.81–0.91). Exposures associated with steel but not iron production (where no excess was observed) might include alloying metals. This excess mortality in steel production supports findings at two other steel plants [Finkelstein and Wilk, 1990; Finkelstein et al., 1991].

Having ever worked in stainless steel production significantly elevated the risk of cancer deaths (liver, stomach, and lung). Excess lung cancer was observed in French stainless steel operations [Moulin et al., 1993]. Exposures of concern include chromium for lung cancer but carcinogens in the stainless steel environment affecting the liver or stomach are not recognized. A possible role for coaltar related emissions from carbon electrodes in electric furnaces [Donato et al., 2000] or coatings [Finkelstein and Wilk, 1990] applied to mold surfaces could not be evaluated.

Explanations for the high rates of fatal injury in the first year of employment include: insufficient training and risk-taking in new employees; placement of new employees in more hazardous jobs; or, high risk individuals leaving employment during the first year as a result of injury or other reasons. For the injuries associated with *increasing* duration in material handling/construction, some cumulative effect is unlikely. Rather, there may be a progression in job and task assignments that results in higher risk in more senior employees. In maintenance, the observed pattern appears to show enhanced risks both at early tenure as well as with increasing duration on the job.

The relative risks of fatal injury by process area observed in this study are much smaller than those reported in a case-control study of the Brazilian steelworker cohort [Baretto et al., 1997]. An important difference in the Brazilian cohort was that actual workplace fatalities were enumerated while in this study work-relatedness was unknown—rate ratios were in comparison to a background rate that included all non-work-related events. Relatively more uniform injury fatality rates across process were also observed in a Chinese steelworker study that did not distinguish work-relatedness [Xu et al., 1996b].

The relatively high fatal injury rate among office workers compared to production workers (SRR = 1.43, Table IV) is difficult to interpret. Using external cause codes, office workers were found to have higher crude death rates than production workers from vehicle-related accidents (n = 53, SRR = 1.47) and higher suicide rates (n = 17, SRR = 1.64); these deaths accounted for 67% of office worker injury deaths. On the other hand, office workers also had more than their share of deaths due to electrocution (n = 3) or toxic gas exposure (n = 3), indicating possible exposure at work not accounted for by their job titles.

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