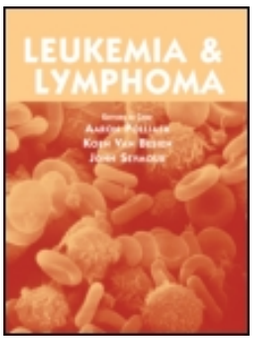

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Leukemia among male construction workers in California, 1988–2007

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Abstract

A total of 18 708 male cases of leukemia from the California Cancer Registry, including 1703 cases usually employed in construction, were each matched with up to five controls from the same source who were diagnosed with cancers not thought to be related to exposures common in construction. Compared to other workers, construction workers were found to have a significantly elevated risk for all leukemia combined (morbidity odds ratio [MOR] = 1.14, 95% confidence interval [CI] = 1.08, 1.20), acute lymphocytic leukemia (ALL) (MOR = 1.30, 95% CI = 1.07, 1.58), acute myeloid leukemia (AML) (MOR = 1.15, 95% CI = 1.03, 1.27) and chronic myeloid leukemia (CML) (MOR = 1.25, 95% CI = 1.09, 1.44). Among the different construction occupations, the highest MOR for all leukemia was among carpet installers (MOR = 1.99, 95% CI = 1.16, 3.44), followed by plumbers (MOR = 1.28, 95% CI = 1.03, 1.59) and laborers (MOR = 1.26, 95% CI = 1.12, 1.42). Other associations were limited to specific construction occupations, leukemia subtypes and/or racial/ethnic groups. These associations should be further studied with more in-depth exposure assessment.

Keywords: Cancer, leukemia, surveillance, construction, occupational, floors and floor coverings

Introduction

Leukemia arises from malignant transformation of stem or progenitor cells that produce blood cells [1]. Leukemia classification systems have changed over time, but have generally included four major categories, based on the rapidity of disease progression and cell lineage: acute lymphocytic (ALL), chronic lymphocytic (CLL), acute myeloid (AML) and chronic myeloid (CML). The rarity of individual leukemia subtypes and difficulties in classification have hampered the elucidation of risk factors, but there are clearly racial and age differences in leukemia incidence, and various physical and chemical agents have been established as or hypothesized to be leukemogens. Occupational exposures that have been classified by the International Agency for Research on Cancer (IARC) as definitely (Group 1) related to leukemia include ionizing radiation, benzene and ethylene oxide, while some non-arsenical insecticides and formaldehyde have been classified by IARC as probably (Group 2A) related to leukemia [2]. Employment in boot and shoe manufacturing and repairing, and the rubber industry, have also been classified as Group 1 by IARC, due to associations that are suspected to be caused by exposure to benzene and other solvents. Exposure to solvents and many more substances that are possibly leukemogenic occur throughout a wide variety of industries, including the construction industry [3].

A recent evaluation of the occupational burden of cancer in Great Britain suggested that over 50% of occupationally related cancer registrations among men are attributable to work in the construction industry [4]. Many different types of cancer have been consistently associated with exposure to various carcinogens in the construction industry, including mesothelioma and lung, stomach, bladder and non-melanoma skin cancers [3–5]. A 1993 review of literature and data sources on construction laborers by Burkhart *et al*. found evidence of an increased risk of mesothelioma, and possibly leukemia, based on studies using cancer registry data [6]. Since then, individual studies have suggested elevated risks of leukemia among workers in various construction occupations or with specific construction-related exposures, but results have been inconsistent. Examples include increases in: all leukemia combined among painters [7,8]; CLL among general construction workers [9], workers exposed to brick mortar [10] and builder's laborers [11]; AML among building trades workers [11]; and acute promyelocytic leukemia (a subtype of AML) among workers in the general construction industry [12].

Construction workers are a difficult population to study because they are highly mobile [13]. This makes it difficult to assemble a cohort of these workers. Labor unions are the only work-related institution with relatively stable, concentrated numbers of construction workers, but in 2005 only 14%

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of construction workers were union members [14]. On the other hand, all construction workers who are diagnosed with cancer in a population-based cancer registry's catchment area should be able to be identified and studied if the cancer registry collects occupational information on all cases.

In addition to variations in risk of occupational hazardous exposures and resulting injuries and illnesses associated with employment in different industries and occupations, there has recently been increasing interest in disparities in the risk of occupational hazardous exposures and resulting injuries and illnesses among workers of different race/ethnic groups, even within the same job categories [15]. These disparities may be related to multiple factors, including workplace discrimination, ineffective training, inadequate communication due to literacy or language barriers, and pressures to accept risky work assignments due to economic insecurity [15].

The purpose of this analysis was to use data from the California Cancer Registry (CCR) to describe the risk of leukemia across various construction occupations, and in four broad race/ethnicity categories of workers: non-Hispanic white, non-Hispanic black, Hispanic and Asian. All leukemia cases combined in addition to major subtypes were examined.

Methods

Study population

This study is part of an ongoing collaboration between the National Institute for Occupational Safety and Health (NIOSH), the California Cancer Registry (CCR) and the Los Angeles Cancer Surveillance Program (LACSP) using data compiled by the CCR, as described previously [5]. For each case of malignant cancer identified in California, the CCR collects three types of information: demographic information, information about the cancer, and treatment and follow-up information. Demographic information includes name, date of birth, race, sex and usual industry and occupation (I&O). Information on lifestyle factors, such as tobacco and alcohol usage, is not captured by the CCR. Information on the cancer includes the site of the cancer, histology, date of diagnosis and stage at diagnosis. The CCR requires that "every effort be made" to capture usual I&O on every cancer case detected by CCR ("Cancer Reporting System Standards Volume 1"). These data are captured in narrative form by registrars, and standardized systems are available for coding both industry and occupation to facilitate analysis. Between 1972 and 2002, the CCR and LACSP coded the I&O of many of their cases to the US Bureau of the Census (BOC) codes [16], but coding was not completed due to resource limitations. Beginning in 2007, NIOSH began a collaboration to complete assignment of 1990 BOC I&O codes to all CCR cases with I&O narratives.

Between 1988 and 2007, a total of 2 894 256 cases of cancer were identified by the CCR. Of these, 1 383 468 (48%) had sufficient narrative information to code industry and/or occupation. For the remaining cancer cases, the industry and occupation fields were blank or filled with "unknown/unemployed/disabled" (26% of the total), "retired" (17%), "homemaker" (6%), "never worked" (3%) or military (0.6%). Data for most cases treated in military treatment facilities are not shared with state cancer registries. In order to identify all cancer cases among construction workers, the I&O fields were extensively searched for key words consistent with construction employment, and the identified cases were coded. Because CCR removed personal identifiers from the data prior to submission to NIOSH and because this study was considered public health surveillance, this study was exempt from consideration by the federal Human Subjects Review Board.

Case–control methods

Case–control methodology was used to assess the risk of all leukemia and major leukemia subtypes among construction workers compared to non-construction workers. The risks of all leukemia and four major leukemia subtypes (AML, CML, ALL, CLL) were also compared across various construction occupations and among construction workers compared to non-construction workers in four broad race/ethnicity strata. Cases and controls were obtained from the CCR. Excluded were females (of the 73 809 construction workers in the CCR database between 1988 and 2007, only 3509 [5%] were female), homemakers, those whose usual industry and occupation were unknown, those who never worked and those in the military. Leukemia cases were included if they were between the ages of 18 years and 97 years at diagnosis, and were diagnosed between 1988 and 2007 (2007 was the most recent year of complete data at the time of analysis). Controls were cases in the CCR database with one or more primary cancers not known to be associated with exposure to the known and suspected carcinogens common in the construction industry (e.g. benzene, formaldehyde): prostate, colon, brain, kidney, bones and joints, and thyroid. Up to five controls were matched to each case based on age at diagnosis (5-year age group), year of diagnosis group (5-year group) and race/ethnicity. We treated individuals with multiple primary cancers as follows: (1) if any of the primary cancers was leukemia, the individual was analyzed as a case, using all data associated with the earliest diagnosed leukemia; (2) if none of the primary cancers was leukemia, but included one or more of the control cancer types, the individual was analyzed as a control, using all data associated with the earliest diagnosed control cancer type.

Data analysis

SAS v. 9.2 software was used for data management and analysis [17]. Student's *t*-tests were used to compare age at diagnosis between construction and non-construction workers.

Morbidity odds ratios (MORs) were estimated by conditional logistic regression using the PROC PHREG procedure, and 95% confidence intervals (CIs) were estimated using the Wald test [18,19]. The MORs were used to compare the proportions of construction workers among the cases and controls. MORs were also estimated for specific construction occupations, for the four different race/ethnicity groups (i.e. non-Hispanic white, non-Hispanic black, Hispanic and Asian) and for each 5-year time period (i.e. 1988–1992, 1993–1997, 1998–2002, 2003–2007). Significant differences between MORs were identified by dividing the difference between the specific regression coefficients by the standard error of the difference, and assuming that the ratio was

distributed as a standard normal variable. Statistical significance was defined as $p < 0.05$.

Results

A total of 18 708 male cases of leukemia, including 1703 cases among males with usual I&O within the construction sector, were identified between 1988 and 2007. The distributions of leukemia cases by subtype and industry are provided in Table I. The proportion of leukemias classified as ALL (9.5% vs. 8.4%) and CML (16.3% vs. 15.1%) was higher among construction workers compared to non-construction workers. Mean age at diagnosis was slightly, but significantly, lower among construction workers compared to non-construction workers for all leukemia cases (58.8 vs. 60.0; $p < 0.05$) and for AML (57.6 vs. 59.2; $p < 0.05$). The cases were matched to 87 450 controls. Most of the controls had either prostate (55%) or colon (25%) cancer. Construction workers had a significantly elevated risk for all leukemia combined over the whole time period studied (MOR = 1.14, 95% CI = 1.08, 1.20; Table II), and during the intervals 1988–1992 (MOR = 1.20, 95% CI = 1.08, 1.34; Table III) and 1998–2002 (MOR = 1.16, 95% CI = 1.04, 1.30; Table III); but, the MORs for each time period were not statistically significantly different from each other. Construction workers also had a significantly elevated risk for ALL (MOR = 1.30, 95% CI = 1.07, 1.58), AML (MOR = 1.15, 95% CI = 1.03, 1.27) and CML (MOR = 1.25, 95% CI = 1.09, 1.44) over the whole time period studied (Table IV). The MORs for each leukemia subtype were not statistically significantly different from each other.

Among the different construction occupations, the highest MOR for all leukemia combined over the entire study period was among carpet installers (MOR = 1.99, 95% CI = 1.16, 3.44; Table II), and this risk appeared to increase over time, but the time-period specific MORs were not significantly different (Table III). The 19 cases of leukemia among carpet installers included seven cases each of ALL and AML and one case each of CLL and CML (Table IV). The MOR for ALL among carpet installers could not be calculated because there were no carpet installers among the matched controls. The MOR for AML among carpet installers was 2.76 (95% CI = 1.06, 7.19). Laborers had a significantly elevated risk for all leukemia combined over the entire study period (MOR = 1.26, 95% CI = 1.12, 1.42; Table II). The MOR for laborers for the period 1993–1997 was significantly lower than the MORs for each of the earlier and later time periods (Table III). Laborers also had a significantly elevated risk for ALL (MOR = 1.66, 95% CI = 1.17, 2.36; Table IV) and AML (MOR = 1.33, 95% CI = 1.06, 1.65; Table IV), and elevated, but not statistically significant, risks for CML and CLL; these MORs were not significantly different from each other. A total of 367 cases of leukemia (including 53 cases of ALL, 87 cases of CLL, 111 cases of AML and 61 cases of CML) and 1298 controls were coded as laborers in the construction industry. In our analyses, construction "laborers" were defined as cancer cases coded to the construction industry (1990 BOC industry code 066), with occupational narrative information assigned to the 1990 BOC occupation code 599 ("Construction trades, not elsewhere classified," $n = 54$) or 869 ("Construction laborers," $n = 1611$). Most of the occupational narratives assigned to the BOC code 869 consisted of some variation of the words "construction," "construction worker," "laborer" or "handyman." Plumbers had a significantly elevated risk for all leukemia combined (MOR = 1.28, 95% CI = 1.03, 1.59; Table II), and elevated, but not statistically significant, risk for CLL, AML and CML over the entire study period. Neither apparent differences by time period in the risk for all leukemia combined among plumbers nor differences in the MORs for specific leukemia subtypes among plumbers varied significantly (Tables III and IV). Operating engineers did not have a significantly elevated risk for all leukemia combined, except during the period of 1998–2002 (Table III); but, they had a statistically significantly increased risk of CML over the entire study period (MOR = 1.91, 95% CI = 1.06, 3.42; Table IV). Neither electricians nor metalworkers had significantly elevated risks for all leukemia combined; but, electricians had a statistically significantly increased risk of AML (MOR = 1.46, 95% CI = 1.07, 2.00), and metalworkers had a statistically significantly increased risk of ALL (MOR = 7.50, 95% CI = 1.25, 44.9) and CML (MOR = 2.63, 95% CI = 1.03, 6.72; Table IV) over the entire study period. Other occupational groups with statistically significantly elevated MORs for all leukemia

Table I. Distribution and mean age at diagnosis of male cases of leukemia with employment history in California Cancer Registry by leukemia type and usual industry of employment, 1988–2007.

		Construction workers		Non-construction workers	
Type (SEER code*)	Total (n)	n (%)	Mean age at diagnosis (standard error)	n (%)	Mean age at diagnosis (standard error)
All leukemia cases	18 708	1703 (100%)	58.8 (0.4)†	17 005 (100%)	60.0 (0.1)
Acute lymphocytic leukemia (35011)	1583	162 (9.5%)	40.6 (1.3)	1421 (8.4%)	41.7 (0.5)
Chronic lymphocytic leukemia (35012)	5734	479 (28.1%)	66.7 (0.6)	5255 (30.9%)	66.3 (0.2)
Other lymphocytic leukemia (35013)	1014	85 (5.0%)	57.0 (1.7)	929 (5.5%)	57.3 (0.5)
Acute myeloid leukemia (35021)	5684	517 (30.4%)	57.6 (0.8)†	5167 (30.4%)	59.2 (0.2)
Acute monocytic leukemia (35031)	384	31 (1.8%)	55.1 (2.9)	353 (2.1%)	58.0 (0.9)
Chronic myeloid leukemia (35022)	2849	278 (16.3%)	55.6 (1.1)	2571 (15.1%)	55.5 (0.4)
Other myeloid/monocytic leukemia (35023)	235	35 (2.1%)	62.9 (3.2)	200 (1.2%)	65.8 (1.3)
Other acute leukemia (35041)	656	67 (3.9%)	64.2 (2.1)	589 (3.5%)	66.8 (0.8)
Aleukemic, subleukemic and NOS (35043)	569	49 (2.9%)	67.7 (2.8)	520 (3.1%)	72.4 (0.7)

*Surveillance Epidemiology and End Results (SEER) ICD-O-3 code definitions are available from: http://seer.cancer.gov/siterecode/icdo3_d01272003/
†Mean age at diagnosis among construction workers significantly lower than mean age at diagnosis among non-construction workers ($p < 0.05$).
NOS, not otherwise specified.

Table II. Risk of any leukemia by occupation among males in California Cancer Registry with construction as usual industry of employment, 1988–2007.

Occupation (1990 BOC codes)	Construction worker leukemia cases (*n*)	MOR (95% CI) for occupation among leukemia cases vs. control cases
All*	1703	1.14 (1.08–1.20)
Brickmasons (563)	26	1.23 (0.80–1.89)
Carpenters (567, 569)	232	1.04 (0.90–1.20)
Carpet installers (566)	19	1.99 (1.16–3.44)
Concrete and terrazzo finishers (588)	18	1.01 (0.60–1.68)
Electricians (575, 576, 577)	133	1.08 (0.89–1.30)
Laborers (599, 869)	367	1.26 (1.12–1.42)
Managers and engineers (003 - 199)	212	1.11 (0.95–1.29)
Metalworkers (597)	22	1.05 (0.66–1.67)
Operating engineers (844, 848, 849, 853, 855, 856)	69	1.09 (0.84–1.42)
Painters (579, 583, 584)	114	1.01 (0.82–1.24)
Plumbers (585, 587)	109	1.28 (1.03–1.59)
Roofers (595)	32	1.29 (0.86–1.93)
Supervisors (243, 303, 307, 553, 554, 555, 556, 557, 558, 843)	177	1.00 (0.85–1.18)
Welders (783)	21	1.12 (0.70–1.81)
Other occupations†	97	1.13 (0.90–1.41)

*All includes 55 cases with industry coded as construction, but occupation coded as "retired" ($n = 18$) or "unknown" ($n = 37$).
†Other occupations within construction industry with more than 10 cases include tile setters ($n = 15$) and drywall installers ($n = 14$).
MOR, morbidity odds ratio; CI, confidence interval.

combined that were limited to the period 1998–2002 were brickmasons (MOR = 2.84; 95% CI = 1.47, 5.49) and roofers (MOR = 2.19; 95%CI = 1.17, 4.09; Table III). When stratified by race/ethnicity, the risk for all leukemia combined was significantly elevated for each group of construction workers (Table V). The risks for all leukemia combined and ALL were highest in non-Hispanic black construction workers; the risks of CLL and AML were highest in Asian construction workers; and the risk of CML was highest in non-Hispanic white construction workers (Table VI). Among all construction workers, only the MORs for all leukemia combined for non-Hispanic blacks (MOR = 1.49; 95% CI = 1.15, 1.92) compared to non-Hispanic whites (MOR = 1.10; 95% CI = 1.03, 1.18) were significantly different ($p < 0.03$).

Significant differences in MORs for specific occupations stratified by race/ethnicity included a higher MOR for all leukemia combined among Hispanic carpet layers compared to Hispanic controls (MOR = 5.95; 95% CI = 1.90, 18.6) versus the MOR for non-Hispanic white carpet layers compared to non-Hispanic white controls (MOR = 1.18; 95% CI = 0.57, 2.45; $p < 0.02$). Eight of 19 carpet layers with leukemia were Hispanic (including four of seven carpet layers with ALL). Two construction occupations without statistically significant results for all race/ethnicities combined had significant results for individual groups. Non-Hispanic black managers had an elevated MOR for all leukemia combined (nine cases; MOR = 3.35; 95% CI = 1.43, 7.84) that was significantly higher than the MOR for all leukemia combined among non-Hispanic white (185 cases; MOR = 1.13; 95% CI = 0.96, 1.32), Hispanic (nine cases; MOR = 0.57; 95% CI = 0.28, 1.15) or Asian (nine cases; MOR = 1.01; 95% CI 0.49, 2.08) managers. Non-Hispanic black painters had an elevated MOR for CML (four cases; MOR = 10.0; 95% CI = 1.83, 54.6) that was significantly higher than the MOR for CML among non-Hispanic white (17 cases; MOR = 1.64; 95% CI = 0.94, 2.85) and Hispanic (five cases; MOR = 0.82; 95% CI = 0.31, 2.19) painters. There were no cases of CML among Asian painters.

Discussion

We found a slightly elevated risk of all types of leukemia combined among all workers usually employed in the construction industry compared to other workers based on data from cases diagnosed between 1988 and 2007. There were no clear differences in risk over time when stratified by 5-year period. Among the four principal types of leukemia, we found the most significantly elevated risk among all construction workers for ALL (MOR = 1.30) and a slightly less elevated risk for CML (MOR = 1.25). We also found that, compared to non-construction workers, construction workers tended to have a lower mean age at diagnosis for all cases of leukemia combined and for most subtypes, although these differences were modest.

Leukemia among specific construction occupations

Although one of the limitations of using cancer registry data to study occupational associations with cancer is that detailed occupational exposure histories for each case are not available, one of the major advantages of this data source is that it includes numerous cases of cancer from detailed occupational groups. Although the occupational classifications of cases' longest-held jobs may provide only crude estimates of actual chemical exposures, occupational groups represent easily identifiable targets for prevention. We found evidence of elevated risks for all leukemia combined among carpet installers, plumbers and laborers.

According to the Occupational Informational Network (O*NET; see http://www.onetonline.org/), specific tasks performed by carpet installers include joining edges of carpet and seaming edges where necessary, by sewing or using tape

Table III. Risk of any leukemia by occupation among males in California Cancer Registry with construction as usual industry of employment, 1988–2007, stratified by 5-year time period.

Occupation	1988–1992		1993–1997		1998–2002		2003–2007	
	Construction worker leukemia cases (n)	MOR (95% CI) for occupation among leukemia cases vs. control cases	Construction worker leukemia cases (n)	MOR (95% CI) for occupation among leukemia cases vs. control cases	Construction worker leukemia cases (n)	MOR (95% CI) for occupation among leukemia cases vs. control cases	Construction worker leukemia cases (n)	MOR (95% CI) for occupation among leukemia cases vs. control cases
All	450	1.20 (1.08–1.34)	416	1.07 (0.95–1.19)	452	1.16 (1.04–1.30)	385	1.12 (0.99–1.26)
Brickmasons	6	1.08 (0.44–2.64)	2	0.32 (0.07–1.35)	14	2.84 (1.47–5.49)	4	0.87 (0.30–2.51)
Carpenters	71	1.19 (0.92–1.55)	68	1.12 (0.86–1.46)	53	0.87 (0.65–1.17)	40	0.96 (0.68–1.35)
Carpet installers	2	0.84 (0.19–3.79)	5	1.82 (0.64–5.13)	6	2.22 (0.83–5.94)	6	3.66 (1.20–11.2)
Concrete and terrazzo finishers	4	0.66 (0.23–1.87)	4	0.85 (0.29–2.47)	6	2.47 (0.93–6.58)	4	0.85 (0.29–2.49)
Electricians	30	0.94 (0.63–1.40)	38	1.17 (0.82–1.66)	34	0.98 (0.67–1.42)	31	1.26 (0.84–1.89)
Laborers	96	1.44 (1.14–1.82)	71	0.94 (0.73–1.22)	96	1.36 (1.08–1.72)	104	1.34 (1.06–1.68)
Managers and engineers	47	1.09 (0.79–1.50)	57	1.16 (0.87–1.55)	53	0.95 (0.70–1.28)	55	1.28 (0.95–1.73)
Metalworkers	7	0.98 (0.43–2.22)	8	1.63 (0.73–3.63)	2	0.33 (0.08–1.40)	5	1.77 (0.64–4.91)
Operating engineers	21	1.08 (0.67–1.73)	15	0.94 (0.54–1.63)	24	1.65 (1.04–2.63)	9	0.70 (0.34–1.41)
Painters	38	1.21 (0.83–1.75)	23	0.73 (0.46–1.15)	32	1.22 (0.82–1.81)	21	0.88 (0.55–1.40)
Plumbers	35	1.70 (1.15–2.51)	23	1.00 (0.63–1.58)	31	1.35 (0.90–2.03)	20	1.07 (0.65–1.75)
Roofers	8	1.24 (0.56–2.74)	7	1.08 (0.44–2.65)	15	2.19 (1.17–4.09)	2	0.36 (0.08–1.56)
Supervisors	47	1.04 (0.75–1.42)	50	1.21 (0.89–1.66)	45	1.01 (0.73–1.39)	35	0.78 (0.54–1.11)
Welders	4	0.94 (0.32–2.79)	4	0.81 (0.28–2.33)	4	0.85 (0.29–2.47)	9	1.90 (0.87–4.14)
Other occupations	22	1.13 (0.70–1.80)	25	1.18 (0.76–1.83)	25	1.09 (0.70–1.70)	25	1.11 (0.71–1.73)

MOR, morbidity odds ratio; CI, confidence interval.

with glue and a heated carpet iron, and installing carpet on some floors using adhesive. An association between leukemia and occupational exposure to carpet production has been suggested in the past [20,21], but to our knowledge this is the first epidemiological study to suggest an association between leukemia and carpet installation, possibly because it is the first study to include an adequate number of carpet installers.

O'Brien and Decouflé [21] speculated that the excess in cases of lymphocytic leukemia they found among carpet and textile production workers could have been related to exposure to synthetic rubber in secondary carpet backing, as an increase in lymphocytic leukemia had previously been reported among rubber industry workers [22]. This was consistent with a 1982 report by the IARC that supported a causal association between employment in the rubber industry and leukemia [23] and a review of epidemiological studies of cancer risk in the rubber industry published between 1982 and 1998 that found excess risks of leukemia in most studies [24]. Data were not available for these reports to include an evaluation of cancer risk by specific exposures and processes within the rubber industry, but both reports suggested that the excess risk of leukemia could be attributed to exposure to solvents, particularly benzene (a known carcinogen), in the rubber industry. Benzene exposure has been most strongly linked to AML, but associations have also been found between benzene exposure and ALL and CML [1]. Complaints from consumers about acute health effects (e.g. watery eyes, runny nose, headache) associated with new carpet installation have prompted the US Consumer Product Safety Commission and others to study organic chemical emissions from new carpet samples. Chemicals detected included 4-phenylcyclohexene, alkyl benzenes, dichlorobenzene, bis(2-ethyl-hexyl)phthalate and formaldehyde [25,26]. The latter three chemicals are classified as potential occupational carcinogens according to the *NIOSH pocket guide to chemical hazards* [27]; but, only formaldehyde has been specifically linked to leukemia [2]. Although the investigators cautioned that it was difficult to determine the potential magnitude of health effects associated with these emissions, it is important to note that any hazard presented to consumers from newly laid carpet would be expected to be magnified when applied to the workers installing the carpet, especially when the installation process may involve heating vinyl and plastic to create seams.

Few data are available regarding actual occupational exposures among carpet layers, but at least one study reported solvent and formaldehyde exposure of up to 3–5 times recommended limits during parquet and carpet work [28]. A review of data collected since the late 1970s focusing on occupational exposure to benzene associated with petroleum-derived products, such as solvents and adhesives used in carpet laying and other construction work, indicated that the time-weighted average airborne concentration of benzene in the workplace during use of these products is not expected to exceed recommended limits under most scenarios [29].

Another specific construction occupation significantly associated with all leukemia combined in our study was

Table IV. Risk of major leukemia types by construction occupation among males in California Cancer Registry, 1988–2007.

	ALL		CLL		AML		CML	
Occupation	Cases	MOR (95% CI) for occupation among cases vs. controls	Cases	MOR (95% CI) for occupation among cases vs. controls	Cases	MOR (95% CI) for occupation among cases vs. controls	Cases	MOR (95% CI) for occupation among cases vs. controls
All	162	1.30 (1.07–1.58)	479	1.05 (0.95–1.17)	517	1.15 (1.03–1.27)	278	1.25 (1.09–1.44)
Brickmasons	0	–	10	1.39 (0.69–2.80)	9	1.54 (0.72–3.31)	2	0.49 (0.11–2.16)
Carpenters	25	1.39 (0.87–2.22)	73	1.06 (0.82–1.37)	56	0.83 (0.63–1.11)	36	1.08 (0.75–1.56)
Carpet installers	7	*	1	0.33 (0.04–2.49)	7	2.76 (1.06–7.19)	1	0.51 (0.07–4.05)
Concrete and terrazzo finishers	2	0.59 (0.13–2.66)	7	1.72 (0.73–4.08)	4	0.71 (0.25–2.05)	2	0.64 (0.15–2.78)
Electricians	11	1.26 (0.63–2.52)	27	0.70 (0.47–1.05)	52	1.46 (1.07–2.00)	22	1.21 (0.75–1.94)
Laborers	53	1.66 (1.17–2.36)	87	1.09 (0.87–1.38)	111	1.33 (1.06–1.65)	61	1.22 (0.92–1.64)
Managers and engineers	9	0.86 (0.42–1.78)	71	1.09 (0.84–1.41)	69	1.12 (0.86–1.46)	27	1.20 (0.78–1.84)
Metalworkers	3	7.50 (1.25–44.9)	5	0.61 (0.24–1.55)	4	0.80 (0.28–2.30)	7	2.63 (1.03–6.72)
Operating engineers	2	0.48 (0.10–2.17)	25	1.07 (0.69–1.65)	21	1.23 (0.76–1.99)	16	1.91 (1.06–3.42)
Painters	8	0.64 (0.28–1.48)	26	0.91 (0.60–1.39)	43	1.09 (0.77–1.54)	26	1.52 (0.97–2.39)
Plumbers	7	0.98 (0.42–2.30)	37	1.43 (0.99–2.07)	35	1.30 (0.89–1.90)	17	1.17 (0.68–2.02)
Roofers	6	2.55 (0.85–7.66)	6	0.86 (0.36–2.04)	8	0.82 (0.36–1.87)	5	2.32 (0.77–7.04)
Supervisors	12	0.86 (0.46–1.61)	56	1.00 (0.75–1.33)	51	1.00 (0.74–1.35)	24	0.99 (0.64–1.55)
Welders	0	–	4	0.91 (0.31–2.64)	7	1.56 (0.67–3.66)	4	0.86 (0.29–2.53)
Other	13	1.46 (0.75–2.81)	27	1.04 (0.69–1.57)	21	0.79 (0.50–1.26)	19	1.68 (0.98–2.89)

*MOR undefined because there were no carpet installers among the matched controls.
ALL, acute lymphocytic leukemia; CLL, chronic lymphocytic leukemia; AML, acute myeloid leukemia; CML, chronic myeloid leukemia; MOR, morbidity odds ratio; CI, confidence interval.

plumbing. Plumbers also had an increased risk for three of the four major leukemia subtypes (CLL, AML and CML), but none of these elevations were statistically significant. We know of no previous reports of an association between occupation as a plumber and leukemia except for an elevated standardized incidence ratio (SIR) for leukemia among female plumbers in Denmark reported by Pukkala *et al.* [30]. Because that elevated SIR was based on two observed cases, and none of the other SIRs for leukemia among plumbers (among females in other Nordic countries or among male plumbers in any of the Nordic countries) were elevated, the investigators appear to have considered it a spurious result. According to O*NET, plumbers' tasks include assembling pipe sections, tubing or fittings, using couplings, clamps, screws, bolts, cement, plastic solvent or caulking, or soldering, brazing or welding equipment. It is possible that plumbers are regularly exposed to leukemogenic chemicals during these processes, but that previous cancer studies among construction workers may not have had enough plumbers to detect this association.

Consistent with previous research, we also found an association between employment as a construction laborer and all leukemia combined, ALL and AML. Construction laborers' tasks may include cleaning or preparing construction sites to eliminate possible hazards, and positioning, joining, aligning or sealing structural components, such as concrete wall sections or pipes (O*NET). It is possible that some of these tasks expose general construction laborers to similar chemical hazards to which specialized carpet installers or plumbers are exposed. It is also possible that some cancer cases who worked primarily as carpet installers or plumbers were misclassified in this study as general construction laborers, due to limited occupational information in their medical charts.

We also found evidence of elevated risks for specific leukemia subtypes among metalworkers, electricians and operating engineers. Metalworkers in the construction industry are typically sheet metalworkers who fabricate, assemble, install and repair sheet metal products and equipment, such as ducts, control boxes, drainpipes and furnace casings. Their tasks may involve fastening seams or joints together with welds, bolts, cement, rivets, solder, caulks, metal drive clips or bonds to assemble components into products or to repair sheet metal items. Little is known about potential leukemogenic exposures among sheet metalworkers, and there were few metalworkers included in the present study; but, the high MORs for this group, especially for ALL, suggest a need for further study. Evidence of an elevated risk for leukemia among electricians and other electrical workers has been reported previously [31,32]. It has been suggested that this risk may be related to exposure to electromagnetic radiation; but, the results of studies of leukemia and occupational exposure to electric and magnetic fields have been inconsistent [33]. Operating engineers operate one or several types of power construction equipment, such as motor graders, bulldozers, scrapers, compressors, pumps, derricks, shovels, tractors or front-end loaders to excavate, move and grade earth, erect structures, or pour concrete or other hard surface pavement. Evidence of an elevated risk for leukemia among operating engineers has also been reported previously [34]. It was suggested that this association might be related to ionizing radiation exposures from X-ray testing of pipeline welds,

Table V. Risk of any leukemia among males in California Cancer Registry with construction as usual industry of employment by race/ethnicity, 1988–2007.

Race/ethnicity	Construction worker leukemia cases (*n*)	MOR (95% CI) for employment in construction industry among leukemia cases vs. controls
All	1703	1.14 (1.08–1.20)
Non-Hispanic whites	1233	1.10 (1.03–1.18)
Non-Hispanic blacks	86	1.49 (1.15–1.92)
Hispanics	334	1.17 (1.02–1.34)
Asians	50	1.44 (1.04–2.00)

MOR, morbidity odds ratio; CI, confidence interval.

Table VI. Risk of major leukemia subtypes among males in California Cancer Registry with construction as usual industry of employment vs. non-construction workers by race/ethnicity, 1988–2007.

	ALL		CLL		AML		CML	
Race/ethnicity	Cases	MOR (95% CI) for construction among cases vs. controls	Cases	MOR (95% CI) for construction among cases vs. controls	Cases	MOR (95% CI) for construction among cases vs. controls	Cases	MOR (95% CI) for construction among cases vs. controls
All	162	1.30 (1.07–1.58)	479	1.05 (0.95–1.17)	517	1.15 (1.03–1.27)	278	1.25 (1.09–1.44)
Non-Hispanic whites	71	1.26 (0.96–1.66)	408	1.04 (0.93–1.16)	356	1.11 (0.98–1.25)	198	1.29 (1.10–1.53)
Non-Hispanic blacks	10	2.99 (1.25–7.11)	28	1.34 (0.86–2.08)	22	1.23 (0.75–2.01)	10	1.26 (0.60–2.65)
Hispanics	77	1.25 (0.93–1.67)	38	0.99 (0.69–1.43)	114	1.21 (0.96–1.53)	64	1.15 (0.85–1.56)
Asians	4	1.23 (0.40–3.77)	5	1.47 (0.53–4.02)	25	1.50 (0.94–2.40)	6	1.10 (0.44–2.74)

ALL, acute lymphocytic leukemia; CLL, chronic lymphocytic leukemia; AML, acute myeloid leukemia; CML, chronic myeloid leukemia; MOR, morbidity odds ratio; CI, confidence interval.

electromagnetic field exposure associated with welding, or asphalt fume exposure [34]. Another possible contributor to the increased risk among operating engineers could be exposure to diesel fuel; but, the relationship between diesel fuel and leukemia is also unclear [35]. A recent cohort mortality study of diesel-exposed miners found a slightly elevated, but not statistically significant, increased risk of deaths due to leukemia [36]. In contrast to some previous studies [6,7], we did not find evidence of a significantly elevated risk of all leukemia or any of the subtypes among painters, with the exception of an elevated MOR for CML among non-Hispanic black painters. A possible association between painting and leukemia has been attributed to exposures to benzene-containing solvents, lead and asbestos, which were common to painting processes in the past, but have become less common over time [7]. The higher MOR for CML among non-Hispanic black painters compared to painters in other racial/ethnic groups could indicate differential hazardous exposure among this particular group. The elevated MOR for all leukemia among non-Hispanic construction black managers compared to managers in other racial/ethnic groups also suggests potentially differential exposure within the construction industry.

Patterns by leukemia subtype

One of the strengths of this study was the ability to examine associations between construction occupations and the four major subtypes of leukemia. Despite known and hypothesized differences in the etiology of different leukemia subtypes, however, the MORs for each leukemia subtype were not statistically significantly different from each other in this study. For all construction workers combined and for all three occupational groups with significantly elevated MORs (carpet installers, laborers and plumbers), ALL appeared to be the subtype with the most increased risk. In the general US population, the age-specific incidence rate for ALL peaks at ages 2–4 years, followed by a declining rate throughout the remainder of childhood, adolescence and early adulthood to a nadir at age 40; subsequently, the incidence of ALL rises with increasing age to a second, albeit lower peak among the elderly [1]. Accordingly, epidemiological studies of ALL have generally focused on childhood ALL. These include studies of parental occupational exposure to pesticides, solvents and other chemicals.

Relationships between occupation and CLL have been more widely studied. We found no elevations of CLL risk in the present study that reached statistical significance; however, we did find a non-significant elevation among brickmasons, which is consistent with a previous finding of increased risk of CLL among workers exposed to brick mortar [9]. Our ability to detect an increased risk of CLL among carpet installers was limited by the occurrence of only one case of CLL in this occupational group. The lack of any statistically significant associations between CLL and employment in construction occupations is consistent with the hypothesis that occupational exposure to benzene may be contributing to some of the associations that we observed (e.g. AML among carpet installers), since CLL is the leukemia subtype with the least evidence for an association with benzene exposure in the literature [1].

Among the two main classes of myeloid leukemia, AML both is more common and has been more extensively studied with regard to occupational associations [1]. We found a slightly elevated MOR for AML among all construction workers, carpet installers, electricians and laborers. We found statistically significantly elevated risks of CML among all construction workers combined, metalworkers and operating engineers. These latter two associations have not been reported previously and should be explored further in future studies.

Patterns by race/ethnicity

One of the advantages of studying cancer registry data from California is that California has large numbers of Hispanics, Asians and African Americans, allowing for more detailed analysis by race/ethnicity than would be possible in most states. According to published cancer registry data from North America, rates of total leukemia are highest among non-Hispanic white males, while rates of AML and CLL are highest among both Hispanic and non-Hispanic white males, rates of CML are higher among both Hispanic white and all black males than among non-Hispanic white males, and rates of ALL are highest among Hispanic white males [1]. Rates of total leukemia and the major subtypes tend to be relatively low among Asians.

In our study, we found the greatest evidence for an increased risk of all leukemia combined among construction workers compared to non-construction workers for non-Hispanic blacks. The elevated risk for all leukemia among carpet layers appeared to be especially high among Hispanic workers, but this result was based on small numbers. As described above, we also found some interesting results for some specific occupation–race/ethnicity strata (e.g. non-Hispanic black managers). All of these findings suggest a

need for further study into whether workers of different race/ethnicities within the same occupational groups experience different levels of hazardous exposures.

Limitations

Despite its advantages (e.g. large numbers of cases among many occupational groups), the use of cancer registry data to study associations between occupational exposures and cancers has several limitations. Only a qualitative measure of occupational exposure was available, i.e. longest-held industry and occupation. The CCR requires that "every effort be made" to capture usual I&O on every cancer case detected by CCR (Cancer Reporting System Standards Volume 1). Federal law also requires cancer registries to collect I&O data (Cancer Registries Amendment Act, Public Law 102 - 515). However, the I&O data available in medical records are not well standardized. I&O data are entered into the medical record through a variety of administrative or clinically based mechanisms by physicians, nurses, admitting clerks and other hospital personnel. In addition, the purposes for which such information is collected are often unrelated to identifying occupational exposures. When I&O data are present in the medical record, they may be incomplete, and from an uncertain time frame (i.e. they may represent the current, but not the usual, industry and occupation). Analyses of a large representative sample of US workers found moderate-to-high levels of agreement between current/most recent occupation and longest-held job [37]. As such, even if current employment information constitutes the only available I&O data, it can serve as a reasonable surrogate for longest-held job.

In addition, I&O data were available for only approximately 50% of cases of cancer in the CCR database. The I&O fields for the remaining records were either left blank by the registrars or contained non-useful information (e.g. "retired," "disabled," "unemployed," "homemaker"). We attempted to minimize potential I&O reporting bias by limiting our analyses to cases and controls with enough I&O information to determine that they were workers at one time. Bias would still have been present if construction workers were more or less likely than other workers to have I&O data recorded in the CCR; however, we have no reason to believe that this would be the case. In fact, the lack of an observed association between leukemia and occupation as a painter (an association that has been previously reported in the literature) in this study argues against this type of information bias.

This study involved inter-cancer comparisons. We took great care to eliminate cancers known to be associated with known or suspected leukemogenic exposures occurring in construction from the control group. However, if any of the control cancers are truly associated with these exposures, we may have underestimated the risk of leukemia associated with such exposures in the construction industry and various construction occupations.

Despite the limitations of cancer registry data, there is some evidence that cancer registry studies yield similar results to those from more extensive studies. For example, in 1984 Garabrant and colleagues published one of the first studies that demonstrated an inverse association between physical activity and colon cancer risk using job activity levels based on occupational information in the Los Angeles County Cancer Surveillance Program [38]. Since then, this association has been confirmed by numerous studies of varying designs [39].

Conclusions

Using data from the California Cancer Registry, we found evidence of a significantly increased risk of all types of leukemia combined, ALL, AML and CML among all workers usually employed in the construction industry compared to other workers. We also found several specific construction occupations with significantly elevated MORs for total leukemia or one or more of its major subtypes. These associations should be further studied with more in-depth exposure assessment. In addition, the case–control methods applied in the present study should be expanded to other central cancer registries to look for consistent patterns.

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