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Occupational Determinants of Cumulative Lead Exposure: Analysis of Bone Lead Among Men in the VA Normative Aging Study

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Abstract

Objectives—To examine the relation between occupation and cumulative lead exposure—assessed by measuring bone lead—in a community-dwelling population

Method—We measured bone lead concentration with K-shell X-Ray Fluorescence in 1,320 men in the Normative Aging Study. We categorized job titles into 14 broad US Census Bureau categories. We used ordinary least squares regression to estimate bone lead by job categories adjusted for other predictors.

Results—Service Workers, Construction and Extractive Craft Workers, and Installation, Maintenance and Repair Craft Workers had the highest bone lead concentrations. Including occupations significantly improved the overall model ($p<0.001$) and reduced by −15% to −81% the association between bone lead and education categories.

Conclusion—Occupation significantly predicts cumulative lead exposure in a community-dwelling population, and accounts for a large proportion of the association between education and bone lead.

Keywords

biomarker; bone lead; job exposure matrix; job title; occupation

INTRODUCTION

Negative health effects of lead exposure have been well-documented in the past decades. Even at low exposure levels, lead has been shown to adversely affect the nervous system,

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Conflicts of interest
The authors declare no conflicts of interest.

cardiovascular health, renal system and mortality.(1) Beginning in the 1970s, legislative efforts to reduce environmental lead exposure through the banning of lead in gasoline and paint were largely successful. The National Health and Nutrition Examination Survey (NHANES) documented the prevalence of adults with blood lead levels of 10 μg/dL (0.48 μmol/L) or higher declined from 3.3% in 1988–1994 to 0.7% in 1999–2002.(2)

Despite the reduction of environmental lead exposure, occupational exposures remain a significant source of lead burden in the working population. Research studies have documented high lead exposure and poisoning in specific professions such as automobile mechanics,(3) smelter, battery,(4) iron,(5) lead,(6) and construction workers.(7) These types of studies, however, are usually based on monitoring workers in specific occupations. Other studies have examined determinants of lead exposure among community-exposed populations, but these have generally only considered blood lead—a short-term biomarker, not considered occupation, or only considered occupation crudely, such as blue collar vs. white collar.(8) No study of which we are aware has considered the association between occupation and cumulative lead exposure in a general community sample, likely in large part because of the difficulty of estimating cumulative exposure in such a group. Analysis of lead in bone can provide such an index of cumulative lead exposure. Understanding how occupation affects cumulative lead exposure—in particular using a biomarker that can assess cumulative exposure after that exposure has occurred as bone lead can do—would have important implications for assessing occupational lead exposure contributions to workers health in the absence of data from occupational lead monitoring programs. Furthermore, a complete understanding of non-occupational determinants of lead exposure requires considering specific past occupations as associations with other demographic factors may be accounted for by occupational differences.

In this study, we conducted an analysis of bone lead concentrations in relation to job titles in a population of community-dwelling men in the Boston area, and examined whether occupation in such a group provides additional information about cumulative lead exposure not explained by known demographic predictors of such exposure.

METHODS

Study Population

Our study population is a subgroup of the Normative Aging Study (NAS), a longitudinal study of men established by the Veterans Administration in 1963 when 2,280 men from the Greater Boston area between the ages of 21 and 80 years were enrolled.(9) Men with a history of treatment for hypertension, systolic blood pressure >140 mm Hg, diastolic blood pressure >90 mm Hg, or other chronic conditions, including heart disease, diabetes mellitus, and cancer, were not admitted into the NAS. The attrition rate has been less than 1% annually. NAS subjects have reported for medical examinations every three to five years. During these visits, participants responded to questionnaires on smoking history, education level, food intake and other variables that may influence health.

NAS participants came in for bone lead measurements between 1991 and 2002. After exclusions for measurement uncertainty (see Bone Lead Assessment) there were 863 participants with a valid patella lead measurement and 868 with a valid tibia lead measurement out of 1,320 active participants. NAS participants with bone lead measurements were similar to those without bone lead measurements with respect to several demographic variables.(10) The human research committees of the VA and Harvard School of Public Health approved this research and written consent was obtained from all participants.

Occupation Assessment

NAS participants were asked about their occupation on their regular NAS questionnaires between 1962 and 1980. A total of 40 individual job titles were reported, and we categorized these into the 14 broad job categories of the US Bureau of the Census 2000 classification of private industry employees (Table 1).(11)

Bone Lead Assessment

Bone lead measurements were taken with a K-XRF instrument (ABIOMED, Danvers, MA) at both the mid-tibia shaft (midpoint between the tibial plateau and the medial malleolus) and patella. Mid-tibia (shin bone) is primarily composed of cortical bone with a lead half-life of many decades. Patella (knee cap bone) is primarily trabecular bone and has a lead half-life of a few years.(12) Thirty minute measurements were taken at each site, after each region had been washed with a 50% solution of isopropyl alcohol. The K-XRF beam collimator was sited perpendicular to the flat bony surface of the tibia and at 30° in the lateral direction for the patella. We excluded individuals with patella measurement uncertainty greater than 15 μg/g bone mineral (n=3) and tibia measurement uncertainty greater than 10 μg/g (n=7) because these measurements usually reflect excessive subject movement during the measurement.

Statistical Methods

We used ordinary least squares regression to examine the association between occupation and bone lead concentration. We utilized two approaches in using reports of occupation. ‘Ever report’ considered a participant to be in a given occupational category if the subject ever reported working in that occupation between 1960 and 1982. Therefore, in this analysis, a participant could be considered to have been in more than one occupational group. The ‘only occupation’ approach was restricted to those participants who only reported working in one occupational category between 1960 and 1982. Therefore, in this analysis, each participant was assigned to only one occupational group. We adjusted analyses for other predictors of lead exposure(10) (assessed at the time of bone lead measurement) including, age (linear continuous), race (white, non-white), education (less than high school, high school graduate, some college or technical school, college graduate, graduate/professional school), smoking (never, former, current; and cumulative years smoked as a continuous variable), and alcohol consumption (<2 drinks per day, 2+ drinks per day; and grams/day categorized into: none, 0.1–10, 10.1–50, >50). Indicator variables were created for any missing data. The significance of adding the occupational groups to the model was tested with a likelihood ratio test (LRT) with 13 degrees of freedom. Tests for trend of the education variable were done by including a single ordinal term for the different education categories (less than high school; high school graduate; some college or technical school; college graduate; graduate and professional school) and assessing its significance. SAS (Gary, IN) version 9.2 was used for all data analysis.

RESULTS

The birth year of the study subjects ranged from 1899 to 1943. At the time of bone lead assessment, the mean (SD) age was 67.3 (7.3) years. Demographic characteristics of the study sample are shown in table 2. Table 3 shows the crude mean patella and tibia lead concentrations for subjects ever reporting an occupation in a given group and the mean concentrations adjusted for known predictors of bone lead concentration. The adjusted mean shown can be interpreted as the mean for a 67 year old, white male non-alcohol drinker, never smoker, with a high school education. Because these characteristics are associated with lower bone lead concentrations, the adjusted means are consistently lower than the unadjusted means. In this analysis, the highest patella lead concentrations are among Installation, Maintenance and Repair Craft Workers (repair, mechanic, skilled craft, other craft), and Protective Service Workers (policeman, firefighter, guard). The highest tibia lead concentrations are among Protective Service Workers (policeman, firefighter, guard), and Construction and Extractive Workers (foreman, carpenter, electrician, painter, plumber). The relative ranking of lead concentrations are similar between the crude and adjusted means. The supplemental table shows the crude bone lead concentration by individual job titles.

Table 4 shows the crude and adjusted mean lead concentrations by occupation only for those NAS participants who reported only one occupation group. The highest patella lead concentrations were found among Installation, Maintenance and Repair Craft Workers (repair, mechanic, skilled craft, other craft), and Construction and Extractive Craft Workers (foreman, carpenter, electrician, painter, plumber). The highest tibia lead concentrations were found among Construction and Extractive Craft Workers (foreman, carpenter, electrician, painter, plumber) and Service Workers (both protective [policeman, firefighter, guard] and others [letter carrier, attendant, other service). In this analysis, several occupation groups had small numbers of NAS men and the relative ranking of these occupations tended to vary more substantially from the analysis based on ever reporting of an occupation. However, the relative ranking of occupations with larger numbers of NAS men remained similar in the two analyses.

Adding ever report of an occupation to the model with only the demographic predictors significantly improved the model prediction (patella and tibia: $p<0.001$). The same was seen in the analysis of those only reporting one occupation (patella and tibia: $p<0.001$). In both analyses, the associations with other demographic variables did not change substantially except for education. Table 5 shows the association between education level and bone lead with and without occupation (ever report of a given occupation) also in the model. Including occupation as a predictor substantially reduces the association with education, particular for higher levels of education. The association between having a graduate education compared with a high school degree was reduced by 72.6% for patella bone lead and 69.9% for tibia lead. The reduction of the association with education was more pronounced for the analysis of only men reporting one occupation.

DISCUSSION

In our sample of community-dwelling men, we found that occupation was a significant predictor of cumulative lead exposure—as measured by lead in bone—above and beyond what is predicted by age, race, education, smoking and alcohol consumption, previously described predictors in this cohort.(10) Considering occupation in the prediction of cumulative lead exposure did not change the associations with other demographic predictors, except for education. The contribution of education level to predicting cumulative lead exposure was reduced, in some cases substantially, when occupation was included in models. This suggests that, although there is still an independent contribution of education to cumulative lead exposure, education is to a large degree acting as a surrogate for occupation in predicting cumulative lead exposure. On the other hand, the other demographic factors are not. Thus, specific occupations rather than cruder groupings (or none at all) should be taken into account when considering likelihood of past lead exposure. These data also suggest that bone lead measurements can capture past occupational lead exposure in community-based populations in which occupational lead monitoring programs may be rare.

In our analysis, we found Protective Service Workers to have consistently high bone lead concentrations across bone type and whether we considered multiple occupations or not. This is consistent with reports suggesting that firemen and policeman are prone to have higher lead exposures.(13, 14) Construction and Extractive Craft Workers also tended to have high bone lead measurements. This job category contains foreman, carpenter, electrician, plumber, and painters. Lead-based paint was commonly used in buildings constructed before 1978, and lead in plumbing solder was also frequently used. In addition to residential buildings, commercial buildings, along with structures such as bridges, also contain lead paint.(15) Due to the large reservoir of lead in older construction, workers can be exposed through projects involving demolition, renovation, repair or painting of new building,(16) especially when lead particles are aerosolized—for example, from sanding.(17) Installation, Maintenance and Repair Craft Workers also had high bone lead measurements possibly related to similar exposure scenarios as for Construction workers.

A handful of previous studies have analyzed occupational determinants of lead levels in more general community populations, although few have utilized bone lead measurements. One study in India found that traffic police, bus drivers, and auto-shop workers have higher blood lead levels than office workers. The author suggested that exposure to leaded gasoline played a major role in determining the blood lead levels.(18) In a Swiss population, a study on environmental factors of blood lead levels found blood lead for blue-collar workers to be higher than nonindustrial employees, suggesting pathways of occupational exposure to lead.(19) In a study in the Beirut area, men working in white-collar jobs including offices and retail shops had a mean (sd) blood lead level of 12.7 (3.7) μg/dl, which is statistically significantly lower than blue-collar workers who had a mean of 18.4 (9.8) μg/dl.(20) Two previous studies in the Boston area have examined bone lead measurements and occupation. In the NAS, the simple dichotomy of occupation into “blue collar” or “white collar” found blue collar workers to have higher bone lead levels than white collar workers when adjusted for demographic variables.(21) A study of a separate, predominantly minority community in the Boston area, found the same relationship with blue collar and white collar occupations.(22) Our current findings generally reflect this distinction, with blue collar occupations tending to have higher bone lead concentrations than white collar occupations, although we expand the detail on this observation by considering differences with a more detailed distribution of occupations. Job exposure matrices for lead exposure have not been based on bone lead analyses as estimates of cumulative lead exposure, but our results suggest this could potentially be an approach to pursue in general community settings. Bone lead measurements can be used as a supplement to job exposure matrix methodology, such as professional judgments of industrial hygienists(23–25) and area exposure samplings.(26)

Finally, our study elucidates one pathway in which socioeconomic status can affect health. There is a well-documented relation between socioeconomic disparities and health outcomes; however, the mechanism of the association is not well understood. Socioeconomic status (SES), usually assessed by variables such as income and education, is linked to a wide range of health problems, including cardiovascular diseases, arthritis, cancer, and higher mortality.(27, 28)

Education is often considered a fundamental SES component because it shapes future occupational opportunities and earning potential. It also is linked to access to information and resources in promoting health-seeking behavior. Previous research has shown that education is predictive of cardiovascular diseases.(29) Lead burden in the body has been shown to be associated with hypertension,(30, 31) cardiovascular diseases,(32–34) diabetes, renal function,(35) lower cognitive functions(36) and mortality.(37) Although education predicts lead exposure, our results suggest that some of that is mediated by occupation. Thus, some of the association between education and cardiovascular disease may be explained by occupational lead exposure. Hence, lead exposure from occupational sources, is perhaps one mechanism in which SES ultimately affects health.

Our study is the first to offer a detailed analysis of occupational determinants of lead burden in the community by utilizing bone lead measurements. A limitation of our study was that only men were studied, thus, these results can only be generalizable to women with precautions as lead levels in women may be influenced by differences in bone kinetics such as menopause, estrogen and pregnancy.(38) Finally, our data does not distinguish between occupational exposure and those of environmental sources, such as leaded paint, drinking water, residence location and dietary ingestions. In conclusion, we found occupations in Construction and Extractive Craft Workers and Installation, Maintenance and Repair Craft Workers, and Protective Services to have the highest predicted bone lead levels. Occupation may account for an important portion of the association between education and bone lead.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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What This Paper Adds

1. Lead exposure can be an occupational hazard, but no study has examined the relation between occupation and cumulative lead exposure in a community-dwelling population.
2. We found that in a sample of community-dwelling men occupation was a significant predictor of bone lead concentration—a biomarker of cumulative lead exposure.
3. Occupation accounted for a large part of the well-known association between education and cumulative lead exposure.
4. Our study suggests that some associations between education and health outcomes could be mediated by occupational lead exposures.

Table 1

Reported Normative Aging Study Occupational Titles by US Census Bureau Occupational Groups.

Occupational Group Title for Census 2000	Normative Aging Study Occupational Titles				
Management, Business and Financial Workers	lawyer	accountant	executive		
Science, Engineering and Computer Professionals	engineer	scientist			
Healthcare Practitioner Professionals	doctor				
Other Professional Workers	teacher	professor	other professional	other manager	
Technicians	technician				
Sales Workers	banker	retail	salesman		
Administrative Support Workers	administrative	personnel	clerk		
Construction and Extractive Craft Workers	foreman	carpenter	electrician	painter	plumber
Installation, Maintenance and Repair Craft Workers	repair	mechanic	skilled craft	other craft	
Production Operative Workers	machine operator	factory	other operative		
Transportation and Material Moving Operative Workers	vehicle driver	deliveryman			
Laborers and Helpers	janitor	manual labor	farm		
Protective Service Workers	policeman	firefighter	guard		
Service Workers, except Protective	letter carrier	attendant	other service		

Table 2

Demographic Characteristics of Study Population

Variables	N (total=869)	%
Age (at K-XRF assessment)		
48–59	137	15.8%
60–64	195	22.4%
65–70	241	27.7%
Over 70	296	34.1%
Race		
White	844	97.1%
Non-white	25	2.9%
Education		
Less than high school	86	9.9%
High school graduate	293	33.7%
Some college/technical school	211	24.3%
College graduate	145	16.7%
Graduate/professional school	98	11.3%
No Information	36	4.1%
Smoking status		
Never smoker	257	29.6%
Former smoker	543	62.5%
Current smoker	67	7.7%
No information	2	0.2%
Cumulative Smoking (pack-years)		
0	257	29.6%
1–20	238	27.4%
More than 20	352	40.5%
No Information	22	2.5%
Currently consuming more than 2 alcoholic drinks per day		
More or equal to 2 drinks per day	172	19.8%
Less than 2 drinks per day	649	74.7%
No Information	48	5.5%
Alcohol consumed (grams per day)		
None	49	5.6%
0.1–10	214	24.6%
10.1–50	274	31.5%
>50	288	33.1%
No Information	44	5.1%

Table 3

Unadjusted and adjusted* mean lead levels by ever report of different occupation groups.

Occupation Groups	Patella Lead				Tibia Lead			
	N	Mean (µg/g)	SD	Adjusted Mean (µg/g)	N	Mean (µg/g)	SD	Adjusted Mean (µg/g)
Management, Business and Financial Workers	190	27.7	15.1	30.3	190	19.1	10.7	19.1
Science, Engineering and Computer Professionals	97	24.5	15.4	27.9	98	17.1	10.7	18.5
Healthcare Practitioner Professionals	5	26.8	5.8	27.5	5	20.0	8.8	20.6
Other Professional Workers	274	27.5	15.7	29.2	274	18.4	9.3	17.7
Technicians	37	25.1	15.0	26.2	38	16.9	9.5	16.1
Sales Workers	89	28.6	17.5	29.3	91	19.8	12.7	19.3
Administrative Support Workers	112	29.1	14.4	28.0	113	21.0	11.5	18.5
Construction and Extractive Craft Workers	76	33.4	26.7	30.0	76	25.9	20.0	22.6
Installation, Maintenance and Repair Craft Workers	150	35.6	24.3	35.1	149	24.2	17.5	21.8
Production Operative Workers	30	34.4	26.5	31.4	30	24.3	16.8	20.9
Transportation and Material Moving Operative Workers	22	33.4	18.4	29.4	22	23.1	17.0	18.1
Laborers and Helpers	27	34.9	22.6	28.1	27	26.6	13.2	19.9
Protective Service Workers	198	36.1	21.1	34.6	200	25.8	14.5	23.7
Service Workers, except Protective	51	32.0	16.1	29.6	51	23.8	12.7	19.8

*Adjusted for age, race, alcohol consumption, smoking, and education. Value shown is that predicted for a 67 year old, white male non-alcohol drinker, never smoker, with a high school graduate education.

Table 4

Unadjusted and adjusted* mean lead levels by occupation group among men reporting having remained in the same occupation.

Occupation Groups	Patella Lead				Tibia Lead			
	N	Mean (μg/g)	SD	Adjusted Mean (μg/g)	N	Mean (μg/g)	SD	Adjusted Mean (μg/g)
Management, Business and Financial Workers	51	29	16	27.8	51	18.8	9.7	16.7
Science, Engineering and Computer Professionals	39	22.4	14.3	22.6	39	15.3	11.1	14.1
Healthcare Practitioner Professionals	3	24	6.1	20.8	3	19.7	12.3	18.0
Other Professional Workers	63	27.4	18.1	28.8	63	21.8	8.9	17.3
Technicians	6	32.8	14.9	32.7	6	19.4	13.6	17.6
Sales Workers	21	31	17.6	30.3	21	21.8	9.2	19.7
Administrative Support Workers	24	29	14.9	22.0	24	19.4	10	12.5
Construction and Extractive Craft Workers	16	43.4	22.3	37.7	16	31.7	18.5	26.6
Installation, Maintenance and Repair Craft Workers	48	39.6	21.7	38.5	48	23.9	16.9	22.3
Production Operative Workers	4	16	3.8	24.7	4	9.8	6.4	15.4
Transportation and Material Moving Operative Workers	4	21.8	9.9	24.8	4	9.4	4.8	11.5
Laborers and Helpers	4	34.8	24.4	24.9	4	27	9.9	17.3
Protective Service Workers	181	36.9	21.6	35.8	181	26.4	14.6	23.8
Service Workers, except Protective	13	35.8	19.2	33.8	13	28.2	18.2	24.5

*Adjusted for age, race, alcohol consumption, smoking, and education. Value shown is that predicted for a 67 year old, white male non-alcohol drinker, never smoker, with a high school graduate education.

Table 5

Association* between education and bone lead concentrations with and without adjustment for occupation (n=477).

Educational Attainment	Patella Lead (95% CI), µg/g			Tibia Lead (95% CI), µg/g		
	Without Occupation	With Occupation	% Change	Without Occupation	With Occupation	% Change
Less than high school	4.8 (−0.6, 10.3)	4.1 (−1.3, 9.5)	−14.6%	6.4 (2.7, 10.1)	5.4 (1.7, 9.1)	−15.6%
High school graduate	Reference	Reference	--	Reference	Reference	--
Less than college	−3.9 (−8.5, 0.7)	−2.3 (−7.61, 2.6)	−41.0%	−2.1 (−5.2, 1.1)	−0.6 (−3.8, 2.7)	−71.4%
College graduate	−9.8 (−14.9, −4.8)	−2.8 (−9.5, 3.9)	−71.4%	−6.8 (−10.3, −3.3)	−1.3 (−5.9, 3.2)	−80.9%
Graduate and professional school	−10.6 (−16.1, −5.2)	−2.9 (−10.2, 4.4)	−72.6%	−8.3 (−12.0, −4.6)	−2.5 (−7.5, 2.4)	−69.9%
P-for trend	<0.0001	0.04		<0.0001	0.01	

* Adjusted for age, race, alcohol consumption and smoking.