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Associations of Dietary Calcium Intake and Serum Calcium Level with Blood Lead Levels in Korean Male Lead Workers

Hee Seon Kim,[1] Ok-Young Song,[1] Kyung-Min Kim,[2] Sung-Soo Lee,[3] Young Hwangbo,[3] Kyu-Dong Ahn,[3] Byung-Kook Lee[3]†

Dept of Foods and Nutrition,[1] Soonchunhyang University, Asan, Korea
Dept of Food and Nutrition,[2] Shingu College, Seongnam, Korea
Institute of Industrial Medicine,[3] Soonchunhyang University, Cheonan, Korea

ABSTRACT

A cross-sectional study was performed to estimate the nutritional status of Korean male lead workers and to assess the relationship between calcium nutritional status and blood lead levels. A food consumption survey was conducted by the 24-hr recall method with 118 lead workers and 63 non-lead exposed controls. Blood lead levels were analyzed from whole blood and serum calcium concentrations were also assessed. Results of dietary analysis showed Korean lead workers consumed relatively sufficient nutrients (more than 75% of RDA) except calcium. Mean dietary calcium intake of lead workers was 502.2mg(72% of RDA) while that of the non-lead workers was estimated as 600.8mg(86% of RDA). Intakes of protein, iron, niacin and vitamin C of lead workers were significantly lower than those of non-lead workers. There was a wide range of blood lead levels(5.5 to 73.5μg/dl) observed while mean blood lead level of lead workers was 30.9μg/dl. However, 98% of lead workers showed normal serum calcium concentrations (range ; 8.9 to 10.7mg/dl, mean ; 9.77mg/dl) while 66% of lead workers were estimated to intake a dietary calcium lower than 75% of RDA. Mean blood lead levels of non-lead workers were significantly lower(mean ; 5.1μg/dl, $p < 0.001$) and the serum calcium concentration was significantly higher(mean ; 10.20mg/dl, $p < 0.001$) than lead workers. Results of unadjusted correlation showed that serum calcium level and dietary calcium intake were negatively correlated with blood lead concentration. In a multiple regression of blood lead levels with variables known as affecting blood lead level such as age, body mass index and occupational lead exposure, serum calcium was insignificant while dietary calcium intake showed statistically significant($p < 0.05$) relation. Since calcium is a very important nutrient to reduce hazardous effects of lead, it should be strongly recommended that lead workers need to increase dietary calcium intake. (*J Community Nutrition* 3(2) : 96~102, 2001)

KEY WORDS : calcium intake · serum calcium concentration · blood lead level · lead workers.

Introduction

During the last few decades, the prevalence of high blood lead incidences appears to have declined. However, much concern still remains relatively high in occupational lead exposure regarding the toxicological implications of lead exposure. Various means of eliminating treatment and prevention of occupational and environmental exposure to lead have been looked at intensively, including examination of nutritional influences(World Health Organization 1995 ; United States Environmental Protection Agency 1998). Among many nutritional factors or food components, the effects of calcium on lead toxicity have been explored for several decades(Bogden et al. 1997 ; Mahaffey et al. 1986 ; Stephens & Waldron 1975). More lead is absorbed from the gastrointestinal(GI) tract and causes more toxic effects in the cases of calcium-deficient animals(Bogden et al. 1992 ; Barton et al. 1978 ; Quarterman et al. 1975) as well as human subjects (Heard et al. 1983 ; Ziegler et al. 1978). Most occupational lead exposures, however, are mainly through dust or fumes, so the route of exposure is the pulmonary organ rather than GI tract(Agency for toxic substances and disease registry 1997). Studies on the nutrition effects on lead toxicity with the different route of lead exposure, besides GI tract, have not

†**Corresponding author** : Byung-Kook Lee, Institute of Industrial Medicine, Soonchunhyang University, 23-20 Bongmyung-Dong, Chunan 330-100, Korea
Tel : 041) 570-2480, Fax : 041) 573-4521
E-mail : leebkk@sch.ac.kr

been reported yet. There is a need to evaluate the calcium intake of Korean lead workers by assessing the amount of dietary intake and to ascertain whether the amount of dietary calcium intake could modify blood lead levels even when the route of exposure is not GI tract.

The purpose of the study was to estimate the nutritional status and to identify the relationship among the dietary calcium intake, serum calcium level and blood lead level in male Korean lead workers. The study is aimed only to male subjects since men are usually less familiar with nutritional information than women in Korean society as well as there are more men than women in lead-handling industries. The specific research purposes are to assess the actual nutrient intake levels for Korean male lead workers, to investigate the differences in blood lead levels and calcium intakes of lead workers and non-lead workers and to evaluate the associations of blood lead levels and serum calcium or dietary calcium intake. With the finding of the study, the eventual goal was to establish the dietary guidelines that can be recommended for the workers with occupational exposure to lead.

Materials and Methods

1. Subjects

A convenience sample of 118 male lead workers who have received mandatory special health examinations by the Institute of Industrial Medicine at Soonchunhyang University were recruited from two site-visit examinations at different lead-using facilities. Sixty three subjects without occupational lead exposure were recruited from among those visited Soonchunhyang University Hospital at Chonan for a mandatory annual medical examination for non-lead using industry workers. Participation was voluntary and all participants of the study provided written informed consent before setting the interview schedule.

2. Data collection and analyses

Information about medical history, demographic characteristics, cigarette smoking and alcohol drinking habits were obtained through survey forms. All participants' heights and weights were measured and percent of body fat content was also measured by a portable bioelectrical impedance analyzer(TBF-501, Tanita, Japan). Dietary intakes were assessed with a 24-hour recall method by one to one interview with trained interviewers. In order to obtain detailed descriptions of all foods and beverages consumed and to estimate food portion sizes, food models, standard household measures and natural-sized colored photographs were used as memory aids. Food records were converted to nutrient intakes by using the computerized nutrient analysis program(CAN-pro, Korean Nutrition Society, 1998). Evaluation of nutrient intake was made in reference to the recommended daily allowances for the Korean population(The Korean Nutrition Society, 2000).

Blood lead levels were analyzed by the Zeeman background-corrected flameless atomic absorption method (graphite furnace) using Hitachi Z-8100(Hitachi, Japan) at the Institute of Industrial Medicine, Soonchunhyang University certified reference laboratory for lead in Korea. Serum calcium levels were measured by the spectro-photometric procedure(TBA-40FR biochemical analyzer, Hitachi, Japan).

3. Statistical analysis

Data was entered and analyzed by SPSSWIN 10.0 program. Independent t-tests for general characteristics, nutrients intakes, blood lead levels and serum calcium concentrations between lead workers and non-lead workers and Pearson's correlations of elevated blood lead levels with anthropometric, biochemical and nutritional factors were also conducted.

To minimize extraneous error in estimating calcium intake due to individual differences in total food intake and to reduce potential confounding by total food intake, calcium intake was adjusted for total energy intake. The calorie-adjusted calcium intake for each individual was computed by taking the residual from the regression model in which total caloric intake was the independent variable and the observed calcium intake was the dependent variable, plus a constant equal to the expected intake of calcium for the mean caloric intake of the study population. As the relationship between calcium and energy intakes was non-linear, the regression model to calculate energy-adjusted calcium intake was performed in the natural log scale to improve stability over the whole range of calcium intake level(Willett 1990).

Multiple regression models were used to examine the relation between calcium intake and serum calcium concentration and blood lead levels, controlling for non-nutrient variables, such as age, BMI and occupational lead exposure(group), which were suspected to confound the lead-calcium nutrition association.

Results

Anthropometric characteristics and smoking and alcohol consumption habits of subjects are shown in Table 1 and Table 2. There were no differences observed in subjects' mean age, height, weight and BMI between non-lead workers and lead workers while the average percent of body fat contents of non-lead workers was significantly higher($p < 0.01$) than that of lead workers. The rate of non-smokers was higher in lead workers although more subjects smoked more than 20 cigarettes per day among lead workers than non-lead workers. The duration of smoking for non-lead workers were longer than lead workers. The rate of drinkers was lower in lead workers while more subjects drink more frequently and consume more alcohol in lead workers than in non-lead workers.

Table 3 showed that the overall nutrients intakes of lead workers in Korea were not as sufficient as non-lead workers. However, most nutrient intakes of both

Table 1. Anthropometric characteristics of the study subjects

	Non-lead workers (n = 63)	Lead workers (n = 118)	t-value
Age(year)	40.8(7.4)	38.3(10.2)	1.761
Height(cm)	169.8(4.9)	169.5(6.2)	0.298
Weight(g)	67.7(9.3)	65.7(9.6)	1.368
BMI(kg/m²)	23.5(2.9)	22.9(3.2)	1.215
Body fat(%)	24.6(5.9)	21.6(5.3)	3.578***

Values in parentheses are standard deviations
*** : $p < 0.001$

Table 2. Smoking and alcohol consumption characteristics of the subjects

	Non-lead workers (n = 63)		Lead workers (n = 118)	
Smoking(Cigarattes/day)	frequency	%	frequency	%
None	16	25.4	43	36.5
1≤ <10	3	4.8	3	2.5
10≤ <20	26	41.3	30	25.4
20≤	18	28.6	42	35.6
Smoking duration(years)	frequency	%	frequency	%
1≤ <10	4	6.3	17	14.4
10≤ <20	20	31.7	32	27.1
20≤ <30	20	31.7	21	17.8
30≤	4	6.3	4	3.4
Alcohol(times/week)	frequency	%	frequency	%
None	10	15.9	27	22.9
1 - 2	43	68.3	60	50.8
3 - 4	10	15.9	21	17.8
Over 5	0	0	9	7.6
Alcohol(g/week)	frequency	%	frequency	%
≤90	20	31.7	33	28.0
90< ≤180	18	28.6	23	19.5
180< ≤360	10	15.9	22	18.6
360<	5	7.9	12	10.2

Table 3. Mean daily nutrient intakes of the subjects

Nutrients	Non-lead workers		Lead workers	
	Intake	% RDA	Intake	% RDA
Energy(kcal)	2234.0 (698.1)	91.0	2138.4 (612.4)	86.6
Protein(g)	89.3 (32.7)	128.1	78.0 (28.0)*	111.4
Fat(g)	57.2 (39.8)		51.3 (24.0)	
Carbohydrate(g)	322.9 (77.3)		315.8 (84.4)	
Calcium(mg)	600.8 (231.5)	85.8	502.2 (204.8)**	71.7
Phosphorous(mg)	1286.8 (346.4)	183.8	1172.3 (386.8)	167.5
Iron(mg)	15.8 (14.5)	131.4	11.7 (6.4)**	97.5
Vitamin A(μgRE)	824.4 (462.1)	117.8	665.3 (779.3)	95.0
Vitamin B_1(mg)	1.43(0.93)	111.7	1.39(0.56)	108.7
Vitamin B_2(mg)	1.23(0.54)	83.7	1.14(0.56)	76.9
Niacin(mg)	19.6 (8.04)	118.2	15.3 (6.20)***	91.7
Vitamin C	132.7 (667.0)	189.5	65.9 (35.6)***	94.1

Values in parentheses are standard deviations
* : $p < 0.05$, ** : $p < 0.01$, *** : $p < 0.001$

non-lead and lead workers showed more than 75% of RDA except that calcium intake of lead workers was 72% of RDA. Intakes of protein, calcium, iron, niacin and vitamin C of the lead workers were significantly lower than those of the non-lead workers.

Table 4 shows the average values of blood lead, serum calcium concentrations and energy adjusted calcium intake with percent of RDA values. Mean blood lead levels of the non-lead workers were significantly lower(mean ; 5.1µg/dl, $p < 0.001$) and the serum calcium concentration was significantly higher(mean ; 10.20mg/dl, $p < 0.001$) than lead workers. There was a wide range of blood lead levels(5.5 to 73.5µg/dl) observed while the mean blood lead level of lead workers was 30.9µg/dl. When dietary calcium intake was adjusted with energy intake values, calcium intakes of both lead workers and non-lead workers were calculated less than actual intake and showed a significant ($p < 0.001$) difference, which was even greater than the difference found in the actual calcium intake($p < 0.01$). Since serum calcium concentration is very tightly regulated by physiological homeostasis, 99% of the lead workers showed normal serum calcium levels(range ; 8.9 to 10.7 mg/dl, mean ; 9.77mg/dl) while 59% of the lead workers were estimated as dietary calcium intake lower than 75% of RDA(Fig. 1). Twenty percent of the non-lead workers, however, were in a higher than normal range of serum calcium concentration while about 48% of the non-lead workers showed less than 75% RDA of dietary calcium intake. When blood lead level was categorized as high and low blood lead levels by a level of 25µg/dl as a criteria, 100% of the non-lead workers while 59% of the lead workers showed low blood lead levels.

Unadjusted correlations of blood lead with different variables are as in Table 5. Age and dietary calcium intakes, both actual intake values and energy adjusted values were significantly associated with blood lead levels with correlations above 0.15. Serum calcium concentration was negatively correlated with blood lead concentration with a p-value less than 0.01.

Table 6 summarizes the results of multiple regressions of blood lead levels against age, BMI, group, serum calcium concentration and energy-adjusted dietary calcium intake. Since the three general characteristics variables as a group accounted for 49.9% of blood lead level variations by themselves, the variables are added in the regression to control for variations in blood lead

Table 4. Blood lead and serum calcium levels and energy adjusted dietary calcium intake of the subjects

Variables	Non-lead workers	Lead workers	t
Blood lead(µg/dl)	5.07(1.34)	30.88(15.18)	-12.223***
Serum Ca(mg/dl)	10.20(0.33)	9.77(0.35)	6.850***
Energy adjusted dietary Ca intake(mg)	573.28(203.18)	484.29(161.03)	3.263***
% RDA of energy adjusted Ca intake	81.9%	69.0%	

Values in parentheses are standard deviations
*** : $p < 0.001$

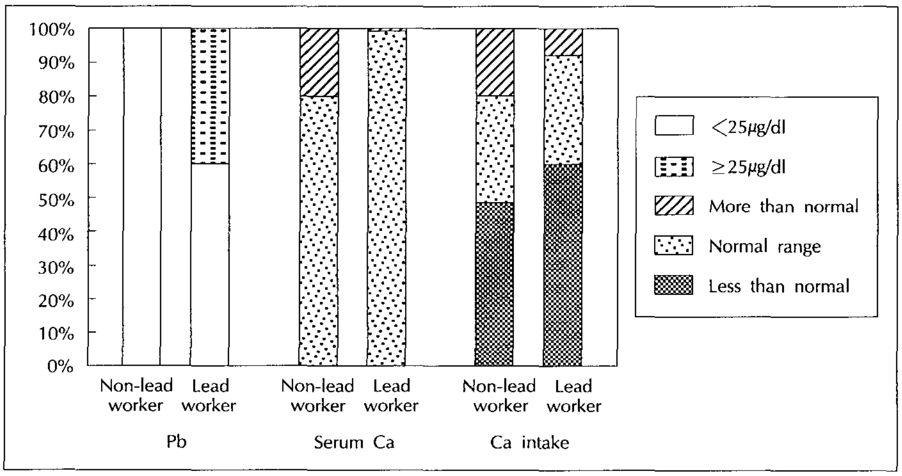

Fig. 1. Diagrams to show the distributions of blood lead levels, serum calcium status and amount of dietary calcium intake of the subjects ; Pb means blood lead levels ; normal range for serum Ca is serum calcium concentrations between 8.8 and 10.6 mg/dL ; normal range for Ca intake is dietary calcium intake between 75% of RDA and 100% of RDA.

Table 5. Unadjusted correlation between blood lead level and anthropometric, biochemical and nutritional factors of the total subjects

Variables	Correlation coefficient
Age	0.183*
Body mass index	- 0.101
Percent body fat	- 0.142
Serum calcium	- 0.372**
Dietary calcium intake	- 0.171*
Energy adjusted calcium intake	- 0.189*

* : $p < 0.05$, ** : $p < 0.01$

Table 6. Multiple regression results of blood lead levels against serum calcium levels and energy-adjusted dietary calcium intakes

Variables	R^2	beta	t value	p value
Model 1	0.499			
Age		0.506	4.968	<0.001
BMI		- 0.343	- 1.082	0.281
Lead exposure		26.706	11.457	<0.001
Model 2	0.513			
Age		0.520	5.060	<0.001
BMI		- 0.380	- 1.206	0.230
Lead exposure		25.351	9.551	<0.001
Serum Ca		- 1.198	- 0.699	0.486
Energy-adjusted dietary calcium		- 0.0238	- 2.005	0.047

level due to general characteristics. Serum calcium and dietary calcium intake account for an additional 1.4% of the blood lead level variation. Blood lead levels are high among the old age and lead industry workers with high statistical significance($p < 0.001$). The effect of energy-adjusted dietary calcium intake on blood lead level is statistically significant at a confidence level of 5%, whereas the effect of serum calcium concentration is statistically insignificant unlike the results from unadjusted correlation, due to the control of variations caused by general characteristics. One percent increase of dietary calcium intake tends to decrease blood lead level by 0.006%.

Discussion

Most of subjects in the current study were in the normal(99% of lead workers and 80% of non-lead workers) or above normal(20% of non-lead workers) range of serum calcium concentration. Although the serum calcium concentrations were adequate, we found the mean serum calcium concentrations were significantly different between the lead and non-lead workers. Because of the findings, we tested whether the source of this significant difference came from the significant difference in blood lead levels between lead and non-lead workers. No significant relation was found between serum calcium concentration and blood lead levels(Table 6) although we observed a significant inverse association between dietary calcium intake and blood lead levels.

In interpreting the results of the current cross-sectional study, however, it should be taken into account that the result may be subject to the following possible misclassification or measurement errors. Firstly, as a tool to measure dietary calcium intake, one day 24-hour recall is certainly not perfect and may involve considerable relative imprecision. In addition, because blood lead is a biomarker of lead accumulation over a certain period of time, a 24-hr recall data may not properly provide information of dietary intake over the time of interest. Nevertheless, it is unlikely that the association we observed can be accounted for fully by the measurement error because the measurement error, if it existed, generally biases the measured association toward the null. The chances for technical error or information bias are not high in this study. Since most of the participants in the present study, either lead or non-lead industry workers, have been participating in the meal plans provided by the company, it is unlikely that the subjects have altered their diets. Also, the dietary nutrients intake was assessed by a highly trained interviewer via one to one interviews with various tools that can make up for the sufficient memory. Secondly, the lack of an appropriate biomarker to validate the results of reported dietary calcium intake may produce a considerable misclassification error. We used serum calcium concentration although it is not considered as a very satisfactory biomarker for calcium status due to its very tight homeostatic regulation(Bronner and Pansu 1999). However, no proper protocol is yet available to compare participants' prolonged low or high calcium intake and to assess participants' histories of calcium intake to confirm the condition of calcium deficiency or repletion in the participants. Our findings of the significant differences of dietary calcium intakes and serum calcium concentrations(Table 3 and Table 4) between lead and non-lead workers could rationalize the choice of serum calcium concentration as a legitimate, though imprecise biomarker of calcium status. The correlation between these two variables, however, did not show a high statistical significance in the current cross-sectional study(data not shown).

Inverse relations between dietary calcium intake and body lead accumulation have been consistently observed in both experimental studies(Bogden et al. 1995 ; Quarterman and Morrison 1975) and epidemiologic studies(Mahaffey et al. 1986 ; Sorrell & Rosen 1977). Calcium has been known not only to inhibit uptake of lead from the gastrointestinal tract, but also to reduce lead retention in the skeleton by modifying the bone metabolism(Cheng et al. 1998). The potential importance of these observations of inverse dietary calcium intake to blood lead level interrelationships is that our findings could be useful to provide an intelligent base for health policy decisions for industry workers, especially for the lead-handling industry workers. There is broad general agreement that primary prevention is the optimal approach to restrictions of exposure to environmental lead(Committee on Lead in the Human Environment 1980). Whereas this broad consensus is widely embraced, the continuing problems of industrial exposure to lead will not be resolved soon. Dedicated efforts to deal with industrial lead exposure must continue to receive prioritized governmental and scientific support and must accompany any type of secondary prevention, such as dietary calcium management aimed at reducing the adverse effects of lead exposure.

Blake and Mann(1983) found that ingestion of milk reduced the 96-hour retention of labeled lead by two fasting adult subjects from greater than 60% of the ingested dose to less than 20%. However, the magnitude of the change in lead absorption produced by milk was smaller than that produced by similar quantities of calcium carbonate and phosphorous, given as an organic salt. Similar findings were reported by Heard and Chamberlain(1982). Thus, there may well be a role for secondary prevention and direct dietary intervention in the industrial lead workers having unacceptably high, or unavoidable, exposure to lead. Public health measures might beneficially be aimed at increasing intakes of calcium and dairy products(with well tolerated forms), particularly in industrial lead workers.

References

Agency for toxic substances and disease registry(1997) : Toxicological profiles for lead. US Department of Health and Human Services, Washington DC

Blake KCH, Mann M(1983) : Effect of calcium and phosphorous on the gastrointestinal absorption of 203 Pb in man. *Environ Res* 30 : 188-192

Bogden JD, Gertner SB, Christakos S(1992) : Dietary calcium modifies concentrations of lead and other metals and renal calbinding in rats. *J Nutr* 122 : 1351-1360

Bogden JD, Kemp FW, Han S(1995) : Dietary calcium and lead interact to modify maternal blood pressure, erythropoiesis, and fetal and neonatal growth in rats during pregnancy and lactation. *J Nutr* 125 : 990-1002

Bogden JD, Oleske JM, Louria DB(1997) : Lead poisoning one approach to a problem that won't go away. *Environ Health Perspect* 105 : 1284-1287

Bronner F, Pansu D(1999) : Nutritional aspects of calcium absorption. *J Nutr* 129 : 9-12

Cheng Y, Willett WC, Schwartz J, Sparrow D, Weiss S, Hu H (1998) : Relation of nutrition to bone lead and blood lead levels in middle-aged to elderly men. *Am J Epidemiol* 147 : 1162-1174

Committee on Lead in the Human Environment(1980) : *Lead in Human Environment.* Washington DC, National Academy of Science

Heard MJ, Chamberlain AC(1982) : Effect of minerals and food on uptake of lead from gastrointestinal tract in humans. *Human Toxicol* 1 : 411-420

Heard MJ, Chamberlain AC, Sherlock JC(1983) : Uptake of lead by humans and effect of minerals and food. *Sci Total Environ* 30 : 245-253

Mahaffey KR, Gartside PS, Glueck CJ(1986) : Blood lead levels and dietary calcium intake in 1- to 11- year-old children : The second national health and nutrition examination survey, 1976 to 1980. *Pediatrics* 78(2) : 257-262

Quarteman J, Morrision JN(1975) : The effects of dietary calcium and phosphorus on the retention and excretion of lead in rats. *Br J Nutr* 34 : 351-361

Quarteman J, Morrision JN, Humphries WR(1975) : The influence of dietary intakes of calcium on lead retention and release in rats. *Proc Nutr Soc* 34 : 89-90

Schwartz J, Landrigan PJ, Baker EL, Orenstein WA, von Linder IH(1990) : Lead-induced anemia : dose-response relationship and evidence for a threshold. *Am J Public Health* 80 : 165-168

Sorrell M, Rosen JF(1977) : Interactions of lead, calcium, vitamin D and nutrition in lead-burdened children. *Arch Environ Health* 32 : 160-164

Stephens R, Waldron HA(1975) : The influence of milk and related dietary constituents on lead metabolism. *Food Cosmet Toxicol* 13 : 555-563

The Korean Nutrition Society(2000) : Recommended dietary allowances for Koreans, 7[th] revision, Seoul

United States Environmental Protection Agency(1998) : Lead in your home : a parent's reference guide. Washington DC : US Government Printing Office

Willett WC(1990) : Implications of total energy intake for epidemiologic analyses. In : Willett WC, ed. Nutritional Epidemiology, pp.245-271, Oxford University Press, New York

World Health Organization(1995) : Inorganic lead. Environmental health criteria 165, WHO, Geneva

Ziegler FE, Edwards BB, Jensen RL(1978) : Absorption and retention of lead by infants. *Pediatr Res* 12 : 29-34