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# Associations of the Heavy Metals Lead, Mercury, and Cadmium with Type 2 Diabetes in the United States Population: National Health and Nutrition Examination Survey (NHANES), 2005-2012

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2013

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## Abstract

Associations of the Heavy Metals Lead, Mercury, and Cadmium with Type 2 Diabetes in the United States Population: National Health and Nutrition Examination Survey (NHANES), 2005-2012

By: Alvin J. Borum

**OBJECTIVE:** The aims of the present study are to determine whether not there is an overall association between heavy metal exposure and diabetes using cross-sectional data from the 2005-2012 National Health and Nutrition Examination Surveys (NHANES).

**RESEARCH DESIGN AND METHODS**: The analysis was restricted to adults that were over the age of 30. In the study sample, 2,738 of the participants identified themselves as having been diagnosed by a physician with diabetes, while 34,757 participants did not self-identify as diabetic. Weighted logistic regression was performed using the proc surveylogistic procedure in SAS with dichotomous outcomes for diabetes. The data for all of the blood concentration measurements for the metals of interest were missing data for 18.14% of the study participant for each metal. Hemoglobin A1C was missing for 14,783 (36.27%) study participants. Only 5.7% of participants were missing self-reported diabetes status data, and 74.11% of the participants were missing urinary cadmium data. Diabetes was defined as either 1) a report of being diagnosed by a doctor or 2) a hemoglobin AIC levels >=6.5%. A weighted linear regression was also performed in SAS with the proc surveyreg procedure, using continuous measurements for hemoglobin A1C as the outcome variable.

**RESULTS:** The weighted multiple linear regression analysis indicated that blood lead and mercury were significantly protective predictors against diabetes. In the weighted logistic regression model, all quintiles of mercury and all quintiles of lead, except for the second, were found to be negatively associated with diabetes. Tests for trend using log transformed lead and mercury were also significant (p-values <0.0001 for lead and mercury). The results of the weighted logistic regression model that utilized self-reported diabetes status as the outcome variable similarly indicated that the continuous mercury and lead variables showed a negative association (p values 0.0114 and <0.0001, respectively). On the other hand, continuous, log transformed urinary cadmium showed a positive association with dichotomized AIC (p-value 0.0302), with odds ratio by quintile being 1.00, 1.016, 1.334, 1.566, and 1.553.

**CONCLUSIONS:** We found that blood lead and mercury may protect against diabetes in these cross sectional analyses. On the other hand, urinary cadmium was associated with increased risk of diabetes. These findings are limited by their cross-sectional nature, which precludes knowing if the exposure preceded the disease.

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# Background

## Diabetes

Diabetes is a disease that causes blood glucose levels to be above the normal range. Glucose is the body's primary energy source, and insulin, a hormone produced by beta cells in the pancreas, is necessary for cells to process glucose [19]. Unlike type 1 diabetes, which involves the destruction of beta cells in the pancreas and reduction in insulin production, the hallmark of type 2 is insulin resistance [13]. For an individual with Type 2 diabetes, the body produces enough insulin to adequately process the glucose in the blood. However, the cells are resistant to the insulin and cannot properly utilize the insulin produced by the pancreas to get glucose into the body's cells. An individual with normal insulin levels and function has a fasting glucose level between 70 and 100 milligrams per deciliter (mg/dL) and a level that is between 135 to 140 mg/dL following a meal. A fasting glucose level between 100 to 125 mg/dL signifies prediabetes, increasing one's risk of developing type 2 diabetes. A fasting glucose level of 126 mg/dL or greater, or a random blood glucose level of 200 mg/dL or higher, will typically lead a physician to diagnose a patient with diabetes [19].

People that have diabetes may exhibit a wide range of symptoms, including frequent urination, excessive thirst, unexplained weight loss, vision changes, numbness in hands or feet, and more frequent infections [19]. Many of the initial symptoms of diabetes are easy to ignore, and some people with the disease have no symptoms at all in the early stages. However, diabetes can ultimately lead to major complications. Gradually, diabetes can increase the risk of cardiovascular disorders, like heart attack and atherosclerosis, neuropathy, kidney failure and end-stage renal disease, and even Alzheimer's disease [19]. The complications of diabetes can be severely disabling or fatal. The scientific community has a fairly thorough understanding of the

lifestyle and genetic risk factors of type 2 diabetes. One of the primary risk factors for type 2 diabetes is being overweight. Studies have shown that excessive fatty tissue correlates to insulin resistance in cells. The distribution of excess fat plays a role in type 2 diabetes risk as well. If the body stores fat primarily in the abdomen, the risk of developing the disease is greater than if fat were stored elsewhere in the body. Activity decreases the risk of developing type 2 diabetes because it helps control weight and makes cells more sensitive to insulin [19]. The risk of type 2 diabetes increases with age primarily because people tend to exercise less and gain weight as they get older [19]. In addition, for reasons that are not completely understood, people of certain races, such as black, Hispanic/Latino, and Native Americans, are more likely to develop type 2 diabetes than white Americans. Smoking, low-income, and lack of education have also been shown to significantly increase the risk of type 2 diabetes. The burden of diabetes in the United States and globally is rising steadily. According to the CDC, 9.3% of the American population have the illness, and as many as 27.8% of those with diabetes remain undiagnosed [13]. In 2008, the World Health Organization estimated that there were 347 million people worldwide with diabetes, with the type 2 variety accounting for more 90% of all cases [7]. According to death certificate data collected by the CDC in 2010, diabetes is the seventh leading cause of death in the United States [13]. Also, diabetes accounts for $176 billion in annually in direct medical costs and another $69 billion in indirect costs to the United States, due to disability, work loss, and premature death [13]. While lifestyles changes are often enough to manage type 2 diabetes, many diabetics have to receive insulin injections in order to combat the illness.

**Mercury**

Mercury is widespread and persistent in the food chain [7]. The metal is naturally occurring and can enter the environment following the natural breakdown of minerals in rocks and soil. Human activities, however, contribute to as much as two-thirds of the total amount of mercury released into the environment. Approximately 80% of the mercury released as a result of human activity comes from fuel combustion and industrial processes [18]. Industrial wastewater containing mercury can enter water sources, and human activities can increase the amount of mercury in the soil, which can ultimately lead to the contamination of water sources [18]. People in the United States are primarily exposed to mercury by ingesting seafood that contains the metal. Mercury exposure has been shown to alter the function of pancreatic beta-cells [7].

**Cadmium**

Cadmium is released into the environmental as a result of various manufacturing process, such as mining and smelting [2]. After entering the environment, cadmium enters the food chain by contaminating soil and water, and is subsequently taken up by plants and animals that are consumed by humans. Shellfish, cereal grains, and potatoes are some of primary sources of cadmium exposure. Tobacco also ardently takes up cadmium, making chewing tobacco and smoking two of the chief routes of human exposure to cadmium [2].

**Lead**

Lead exposure is another serious issue in the U.S. At least 4 million households with children living in them are contaminated with lead [3]. There are no safe levels of lead exposure, and the neurological systems of children are especially vulnerable to the adverse health effects lead exposure can cause. Since the EPA mandated that lead additives be phased out of gasoline in the 1980's, blood lead levels have drastically decreased among children and adults in the U.S [8]. However, roughly 11% of U.S. households where children reside have high levels of lead, facilitating lead exposure by ingestion or inhalation [3].

## Introduction

The environmental risk factors of type 2 diabetes are understood less than the lifestyle contributing factors. Several studies have noted an association between type 2 diabetes and polychlorinated biphenyls. Using NHANES data, Patel and other researchers found carotenes and the pesticide heptachlor to be positively associated with diabetes. However, results from studies showing an association between heavy metals (i.e. lead, mercury, and cadmium) and diabetes have been less consistent. Patel was unable to detect any significant association between heavy metals and diabetes during his analysis [14]. A Korean study, using data from a Korean national health survey, were also unable to identify a link between heavy metals and diabetes [12]. However, a 2002 study conducted by Schwartz and others concluded that cadmium was indeed associated with fasting glucose levels and diabetes. Using data from the NHANES III, Schwartz analyzed data from 8,722 of Americans over the age of 40, and determined that there was a significant positive association with urinary cadmium and both fasting glucose and diabetes [15]. The study found that the odds of impaired fasting glucose and diabetes increased as urinary cadmium increased (impaired fasting glucose odds ratio = 1.48, 95% CI 1.21-1.82; diabetes OR = 1.24, 95% CI 1.06-1.45). The Schwartz study also mentioned that cadmium exposure causes diabetes in rats and mice by destroying beta cells in the pancreas of the animals and increasing insulin resistance [15]. In a study conducted by Wallia, researchers identified an association between urinary cadmium levels and pre-diabetes in 2005-2010 NHANES data [20].

Studies conducted in Taiwan indicated that people in the joint highest tertile of mercury and dioxin exposure had 11 times the risk of insulin resistance in comparison to those at lower levels of exposure (AOR 11.00, 95% CI: 4.86, 26.63). In the study, which included 1449 non-diabetic participants, Chang and others also found an association between mercury exposure and

the occurrence of metabolic syndrome [4]. Metabolic syndrome is a group of ailments, like high blood sugar and high body fat, which can increase risk of developing type 2 diabetes [4].

A study conducted by Afridi and other researchers discovered that lead and cadmium levels in adults living in urban areas of Ireland and Pakistan were higher in diabetic individuals than those without diabetes ($P<0.001$) [1]. An association between higher levels of lead exposure and higher levels of fasting blood glucose were also observed in a study conducted by Serdar and others in Turkey ($P<0.05$) [17]. A study conducted by Ettinger in 2014 among young black adults from the United States, Jamaica, and various African nations (N=500 from each site) found an association between higher lead levels and higher fasting blood glucose levels (OR 4.0, 95% CI: 1.6, 9.6) [5]. Ettinger and his team did not note any statistically significant association between high blood glucose and exposure to mercury or cadmium. Exposure to heavy metals is shown to be higher in groups that exhibit increased risk of type 2 diabetes [5]. There are statistically significant racial differences in urinary cadmium levels, with higher levels being observed in black and Hispanic women in comparison to white non-Hispanic women [11]. According to studies conducted by the CDC, low-income, black Americans, and Hispanic Americans are associated with higher levels of lead exposure [3]. According to an article by Kuo and others, additional work is necessary to gain a clearer understanding of the potential association between diabetes and lead, mercury, and cadmium [7].

Because type 2 diabetes is such a major issue, identifying risk factors that can be prevented easily would be a great step in mitigating the direct and indirect costs associated with the illness. Given that the chances of being exposed to heavy metals is still very real globally and the association between these substances and diabetes has yet to be definitively established or

disproven, it is important to fully assess the factors that may influence the relationship between heavy metals and diabetes.

**Goals of Present Study**

The aims of the present study are to determine whether not there is an overall association between heavy metal exposure and diabetes. If there is an association between types 2 diabetes and heavy metal exposure in the study, researchers can provide policymakers with better recommendations for diabetes prevention. For example, regulations aimed at limiting the amount of cadmium released into the environment via manufacturing processes could be considered. Initiatives like the Health Homes Programs could be expanded to aid in decreasing exposure to lead dust and decreasing mercury in the diet. Currently, the Healthy Homes project seeks to reduce children's lead exposure by increasing childhood blood lead surveillance, technical capacity and training among public health workers, and developing case management guidelines [3].

# Methods

## Study Design and Population

The data sets for the analysis come from the National Health and Nutrition Examination Survey (NHANES) conducted by the National Center for Health Statistics of the Centers for Disease Control and Prevention. The sample for NHANES is selected to represent the entire population for the United States, and certain populations, such as black and Hispanic Americans, are over-sampled in order to produce reliable statistics concerning those groups. Information concerning demographic characteristics, ethnicity, and medical history were obtained via interview, while the blood and urine samples were obtained via physical examination and analyzed in a laboratory. The study utilized NHANES data from 2005-2012. The analysis was restricted to adults that were over the age of 30. In the study sample, 2,738 of the participants identified themselves as having been diagnosed by a physician with diabetes, while 34,757 participants had not been diagnosed with diabetes.

## Study Variables

The primary outcome variables of the study were self-reported diabetes status and hemoglobin A1C percentage. Data concerning the race, age, sex, income, smoking status, and body mass index (BMI) were obtained from questionnaire and examination data in NHANES and included in the analysis. All of these variables have been linked to the occurrence of diabetes [19]. Blood samples were utilized to determine the serum concentrations of lead, cadmium, and mercury. As previously stated, a number of studies have found associations between this heavy metals and diabetes, while some have found no association. Our analysis intends to aid in resolving the controversy. Using inductively coupled plasma mass spectrometry, researchers

were able to determine whole blood concentrations for lead, cadmium, and mercury [21]. This technique involves the use of ICP-MS technology, which is useful for detecting substances in low concentrations. All individuals below the limit of detection for each heavy metal were retained in the analysis and were assigned a blood level for the exposures equal to LOD/√2 [21]. The data indicated that 5,860 (35.09%) participants had blood cadmium readings below the LOD. For mercury and lead, 6,607 (19.8%) and 114 (0.68%) participants, respectively, had blood concentrations below the LOD [Table 1]. Analyses was performed with heavy metal exposure included in the model as a continuous variable (log transformed) and with the exposures divided into quintiles to see if any monotonic relationship exists. Diabetes was defined using hemoglobin A1C percentage and self-reported questionnaire data. Hemoglobin A1C is capable of reflecting a person's plasma glucose for up to 120 days prior to test. The ability of hemoglobin A1C testing to show plasma glucose levels for the last 120 days potentially makes it a much more stable measure for diabetes status than fasting blood glucose measurements or random blood glucose testing [21]. The most recent clinical recommendations suggest defining a hemoglobin A1C level of 6.5% or greater as diabetes [21]. NHANES participants were also asked if a physician had ever diagnosed them with diabetes or pre-diabetes. Given that people diagnosed with diabetes are mostly liked working with a physician to control their blood glucose levels, the questionnaire data and the hemoglobin A1C percentage were both used as outcome measures.

Smoking status was accounted for in the analysis by including continuous serum cotinine levels, which is a well-established biomarker for exposure to tobacco products. The serum cotinine levels were measured via isotope dilution-high performance liquid chromatography and atmospheric pressure chemical ionization coupled mass spectrometry [21]. All individuals below

the limit of detection were retained in the analysis and were assigned a blood level for the exposures equal to LOD/√2. The data indicated that 8,753 (38.96%) participants had cotinine concentrations below the LOD [Table 1]. Smoking can be associated with diabetes and the amount of heavy metals present in the body, making the variable a potential confounder that should be controlled for during the analysis [15].

All of the variables utilized in the study had missing data, with the exception of race and sex. The data for all of the blood concentration measurements for the metals of interest were missing data for 18.14% of the study participant for each metal [Table 1]. Hemoglobin A1C was missing for 14,783 (36.27%) study participants, and creatinine and cotinine were missing for 22.13% and 23.65% of study participants, respectively [Table 1]. House income was missing for 32.5% of study participants, while only 5.7% of participants were missing for self-reported diabetes status data. Because urinary cadmium was only measured in a small subsample of NHANES participants [15], 74.11% of the participants were missing urinary cadmium data [Table 1]. The weighted logistic regression model used to analyze the relationship between the blood concentrations of the heavy metals and dichotomized hemoglobin A1C had 21,031 participants [Table 4], while the weighted logistic regression metal analyzing the association between the blood concentrations of the heavy metals and self-reported diabetes status had 20,724 participants [Table 3]. In the logistic regression models where urinary cadmium was the primary predictor of interest and either self-reported diabetes status or dichotomized hemoglobin A1C were the outcome variables, there were 6,509 and 6,605 participants in the respective models [Table 5, 6]. The linear regression model using the blood concentrations of the heavy as predictors and continuous, log transformed hemoglobin A1C as the outcome variable had a total

of 17,226 participants [Table 7], while the linear model using urinary cadmium as the primary predictor of interest had 5,715 participants [Table 8].

In addition to the analyses performed using the blood measurements of the heavy metals, a separate weighted logistic and linear regression analyses were performed using urinary cadmium as the primary predictor of interest. The purpose of including analyses involving urinary cadmium is because urinary cadmium has been proven to be proportional to one's body burden of cadmium and is a more accurate measure of lifetime exposure than blood cadmium measurements, which is a more accurate measure of acute exposure [15]. Also, unlike the analyses focusing on blood concentrations of the metals, the analyses using urinary cadmium had creatinine in the model in order to account for the variations in the diluteness of the urine samples in the NHANES datasets [15].

**Statistical Methods**

The statistical analysis for the study was performed via SAS version 9.4. The SAS proc means were utilized to obtain descriptive statistics for the variables and perform exploratory analysis. The weighted logistic regression was performed using the proc surveylogistic procedure in SAS with dichotomous outcomes for diabetes. Diabetes was defined as either 1) a report of being diagnosed by a doctor or 2) a hemoglobin AIC levels >=6.5% [21]. The weighted logistic regression analysis for both outcome variables was performed twice, once with the metal blood concentrations categorized into quintiles and again with continuous blood concentrations for the heavy metals of interest. Because the measurements for lead, mercury, and cadmium were right skewed, the log transformation of the original measurements were utilized in the analysis in to lessen the influence of extremely high values The weighted linear regression was performed in

SAS with the proc surveyreg procedure, using continuous measurements for hemoglobin A1C as the outcome variable.

# Results

## Comparison of Means of Self-Identified Diabetics and Non-Diabetics

Study participants that reported to have been diagnosed with type 2 diabetes in the NHANES questionnaire data from 2007-2012 exhibited significant differences in age, fasting blood glucose, and BMI, as well as mercury, lead, and cadmium blood levels [Table 2]. The mean values for the aforementioned variables were higher for individuals with diabetes than the study participants that had not been diagnosed for type 2 diabetes by a physician. Also, cotinine levels and hemoglobin A1C percentages were significantly higher among participant that stated that they had been diagnosed with type 2 diabetes. Significant differences in urinary cadmium and creatinine levels were also observed between study participants that identified as type 2 diabetics and those that did not, but in this case, those individuals that did not report a diabetes diagnosis exhibited higher mean concentrations of urinary cadmium and creatinine [Table 2].

## Weighted Linear Regressions

The weighted multiple linear regression analysis utilizing hemoglobin A1C percentage as the outcome variable indicated that lead and mercury negatively associated with diabetes [Table 7]. Cadmium, however, was not statistically significant. According to the model, a one unit increase in lead results in a 0.166 decrease in hemoglobin A1C percentage, adjusting for all other variables. Likewise, a single unit increase in mercury results in a 0.025 decrease in hemoglobin A1C. Cotinine, BMI, and age were significant predictor variables that result in hemoglobin A1C increases for each one unit increase of the respective variable, adjusting for all other variables in the model. The lowest income category, which contained participants with incomes from 0 to $24,999, was significant and resulted in increases in hemoglobin A1C percentage in comparison

to the reference group. The weighted linear regression analysis that included urinary cadmium as the primary predictor of interest determined that urinary cadmium was not a statistically significant predictor of hemoglobin A1C levels [Table 8].

**Weighted Logistic Regressions**

In the weighted logistic regression model that used categorized hemoglobin A1C as the outcome variable, all quintiles of mercury and all quintiles of lead, except for the second, were found to be significant predictor variables in the model [Table 4]. Tests for trend using log transformed lead and mercury were also significant (p-values <0.0001 for lead and mercury), with the odds ratios of mercury and lead being 0.923 (0.830, 1.027) and 0.475 (0.404, 0.559) respectively. The odds ratio for lead exposure hints that the metal may be protective, a trend that was present in the linear regression models. Age, BMI, and cotinine were all found to be significant in the regression model, but the odds ratios for those variables only indicated very weak associations between them and the outcome variable or no association at all. Sex was found to be a significant predictor in the regression model, and the statistically significant odds ratio of 2.002 (1.700, 2.358) indicated that men are twice as likely to have high hemoglobin A1C, adjusting for all other factors.

In relation to study participants with an income between $25,000 and $64,999, participants with lower income were more likely to have higher hemoglobin A1C percentages. All race categories were significant predictors and were much more likely to have high hemoglobin A1C percentages than the reference group, which consisted of white, non-Hispanic study participants. Urinary cadmium was not found to be a statistically significant predictor of hemoglobin A1C levels categorized into quintiles [Table 6]. However, the urinary cadmium

trend test, which utilized log transformed urinary cadmium measurements as a predictor variable for hemoglobin A1C, produced a p-value of 0.0302, indicating that urinary cadmium was a significant predictor in the model [Table 6]. According to the weighted logistic regression in which continuous, log transformed urinary cadmium was a predictor variable, the odds ratios of 1.314 (1.026, 1.683) indicates that the odds of having hemoglobin A1C levels indicative of type 2 diabetes is 1.314 times higher for participants with relatively high amounts of urinary cadmium compared to participants with relatively low amounts of cadmium in their urine.

The results of the weighted logistic regression model that utilized self-reported diabetes status as the outcome variable indicated that all quintiles of mercury and lead were statistically significant predictors, except for the first quintile for each metals [Table 3]. The trend of lead and mercury indicated that there was a significant inverse association between the two metals and self-reported diabetes status, as the continuous mercury and lead had odds ratios of 0.887 (0.808, 0.973) and 0.486 (0.422, 0.560) respectively [Table 3]. Age and BMI were again significant predictor variables, with the odds ratios for the variable, 1.079 (1.073, 1.085) and 1.095 (1.084, 1.107) respectively, indicating that increases in age or BMI, adjusting for other variables, increase the probability of identifying as a diabetic. All race categories were significant predictors and were much more likely to self-report having type 2 diabetes than the reference group, which consisted of white, non-Hispanic study participants [Table 3]. The weighted logistic regression analyses that examined a possible association between urinary cadmium, both categorized into quintiles and as a continuous log transformed variable, and self-reported diabetes status indicated that urinary cadmium was not a statistically significant predictor [Table 5].

## Discussion

As previously stated, the primary goal of this study was to aid in providing a definitive conclusion concerning any possible association between heavy metal exposure and type 2 diabetes. Several studies [12, 14] relying on blood measurements of heavy metals determined that there was no association between exposure to heavy metals and type 2 diabetes, while the studies conducted by Wallia and Schwartz found an association between urinary cadmium and type 2 diabetes [15, 20]. To further complicate matters, the work of Ettinger and others found associations between type 2 diabetes and the heavy metals of interest using blood concentration measurements [5]. Our study does little to completely end the controversy. The results of our analyses suggest no association between blood cadmium concentration and type 2 diabetes but determined that there was a significant association between continuous log transformed urinary cadmium levels and high hemoglobin A1C levels, indicative of type 2 diabetes. These findings are consistent with prior studies conducted by Moon and others [12], showing no association between blood heavy metal concentrations and type 2 diabetes, as well as the studies showing an association between the illness and urinary cadmium levels.

While the study did have a number of findings consistent with previous research, there was a glaring inverse association between type 2 diabetes and blood concentrations of lead and mercury. In the weighted analysis in which the metals were divided into quintiles, lead seemed to become increasingly protective as exposure levels increases, while mercury appeared to have a U-shaped distribution, with the third and fourth quintiles being slightly more protective than the first and fifth quintiles. This finding could be due to confounding by the mineral zinc, which may be protective against diabetes and correlated with the other metals. According to the work of Seo [16] and the work of Miao and others [10], zinc deficiency could potentially be associated with

the development of diabetes and metabolic syndrome. According to the California Department of Toxic Substances Control, many faucets sold in the United States are made from a combination of copper, zinc, and lead [9]. Houses constructed prior to 1986 are likely to have pipes, fixtures, and solder made with this mixture of metals [9]. When residents run water, especially hot water, through the plumbing of an older home, significant amounts of these metals can leach into the water supply. Drinking water with even trace amounts of lead and zinc allows the metals to accumulate in the body over time. Given that zinc exposure can potentially be associated with exposure to other heavy metals, as well as protective against diabetes and diabetes-related ailments like metabolic syndrome, zinc could be creating a spurious protective association between type 2 diabetes and the heavy metals in our study. Because the chief routes of cadmium exposure are the use of tobacco products and the consumption of plants and animals exposed to cadmium-containing industrial waste, cadmium exposure is less strongly associated with zinc exposure, and the spurious associate that could possibly be occurring with the other heavy metals is less likely to occur with cadmium [2].

**Strengths and Limitations**

There were a number of factors that limited the effectiveness of the study. For instance a number of the biological measures had high percentages of missing data. Approximately 70% of the participants were missing measurements for fasting glucose [Table 1]. Because urinary was only measured for a small subsample of the NHANES population, measurements for urinary cadmium were missing for all but approximately 26% of our study population [Table 1]. Also, due to substantial percentages of missing values like income and cotinine measurements (32.50% and 22.13% missing, respectively), it was necessary to exclude participants from the sample

utilized for the analyses. In addition to the missing values, some of the analyses conducted relied upon self-reported data to determine type 2 diabetes status. We attempted to overcome this limitation by also performed analyses utilizing categorized hemoglobin A1C, with 6.5% as the cutpoint, as our outcome variable for the logistic regression analyses. Another notable, limitation is the absence of zinc in the analyses. As a potential confounder, including serum or urinary zinc measurements in the model for adjustment purposes may have strengthened the results of the study. The cross-sectional nature of the NHANES datasets makes difficult determining temporal links between types 2 diabetes and heavy metal exposure. Some improvement is provided by using urinary cadmium, which is accepted as a better indicator of long-term exposure than serum cadmium concentrations, in some analyses. However, the study is still cross-sectional and it is impossible to know whether high urinary cadmium preceded or followed the occurrence of high hemoglobin ACI.

Also, with exposure to heavy metals like lead and cadmium steadily decreasing in the U.S. population, it is possible that effects only visible at extreme exposure levels may have been missed in the more recent NHANES datasets.

Although the analyses performed possessed a number of limitations, the study still included a multitude of strengths. For instance, the sampling design employed in the NHANES allows researchers to generalize findings to the entire population of the United States. NHANES also provided the researchers with readily available measurements for a host sociological and biological factors necessary for adjustments in the linear and logistic regression models. It is also noteworthy that many of this study's findings were in agreement with the results of previous studies on the subject.

## Future Directions

In this study, the researchers determined that urinary cadmium could potential lead to type 2 diabetes and that lead and mercury could potentially be protective factors. However, the cross-sectional nature of the survey data prevents researchers from definitively establishing a causal link. Therefore, it is necessary to conduct a prospective study where heavy metals levels are determined at the outset and incident cases of type 2 diabetes are tracked in order to determine whether or not the associations in the study are causal. The researchers could also perform analyses using data from populations were heavy metal exposure is more prevalent. Lastly, given the role of zinc as a potential confounder, future studies should obtain measurements of serum zinc concentrations and include those measurements in the analyses for adjustment purposes.

## Conclusions

Because the study determined that cadmium exposure could potentially increase people's chances of developing type 2 diabetes, public health agencies worldwide could increase efforts to limit cadmium exposure. These efforts could involve greater tobacco, such as raising cigarette taxes, and increasing funding for smoking cessation programs, as tobacco is one of the primary routes of cadmium exposure. Government agencies should implement policies to further regulation industrial sources environmental cadmium pollution. Despite the significant inverse association found between type 2 diabetes and the heavy metals lead and mercury, more research is necessary to verify that link and establish causality. Also, given the myriad of detrimental health effects associated with high levels of lead and mercury exposure, it is doubtful that the metals will be implemented in any type 2 diabetes control strategy.

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**Table 1: Descriptive Statistics on Study Variables, N= 40754**

| | Mean (SD) or n(%) | Number Missing (%) | Number Below LOD (%) |
|---|---|---|---|
| **Age** | 31.24 (24.84) | N/A | |
| **Glucose** | 105.49 (33.26) | 28111 (68.98%) | |
| **Mercury** | 1.23 (2.06) | 7392 (18.14%) | 6607 (19.80%) |
| **Lead** | 1.55 (1.63) | 7392 (18.14%) | 114 (0.68%) |
| **Cadmium** | 0.41 (0.52) | 7392 (18.14%) | 5860 (35.09%) |
| **Hemoglobin A1C** | 5.61 (0.99) | 14783 (36.27%) | |
| **Creatinine** | 126.37 (79.76) | 9018 (22.13%) | |
| **Cotinine** | 40.84 (108.40) | 9640 (23.65%) | 8753 (38.96%) |
| **BMI** | 25.52 (7.66) | 4959 (12.17%) | |
| **Urinary Cadmium** | 0.3111 (0.43) | 30204 (74.11%) | 1391 (13.18%) |
| **Sex** | | N/A | |
| Male | 20243 (49.67%) | | |
| Female | 20511 (50.33%) | | |
| **Level of Education** | | 18098 (44.41%) | |
| Less than High School | 2760 (12.18%) | | |
| High School, no diploma | 3603 (15.90%) | | |
| High School w/ Diploma/GED | 5238 (23.12%) | | |
| Education Past High School | 11055 (48.80%) | | |
| **Household Income** | | 13244 (32.50%) | |
| 0 to $24,999 | 9252 (33.63%) | | |
| $25,000 to $64,999 | 10246 (37.24%) | | |
| $65,000 and Over | 8012 (29.12%) | | |
| **Race** | | N/A | |
| Mexican American | 8735 (21.43%) | | |
| Other Hispanic | 3754 (9.21%) | | |
| White, Non-Hispanic | 15424 (37.85%) | | |
| Black, Non-Hispanic | 9555 (23.45%) | | |
| Other | 3286 (8.06%) | | |
| **Diabetes Status – Self-reported** | | 2325 (5.70%) | |
| Yes | 2738 (7.03%) | | |
| No | 35691(91.69%) | | |
| **PreDiabetes Status - Questionnaire** | | 15179 (37.25%) | |
| Yes | 937 (3.66%) | | |
| No | 24638 (96.16%) | | |
| **Hemoglobin A1C Levels** | | N/A | |
| Normal | 32639 (80.09) | | |
| Prediabetes | 5841 (14.33) | | |
| Diabetes | 2274 (5.58) | | |

**Table 2: Mean Levels of Demographic and Biological Characteristics by Diabetes Status (self reported), Excluding people with Pre-diabetes, N=37,495**

| | Mean (SD) or n(%) with Diabetes N=2738 (7.30%) | Mean (SD) or n(%) without Diabetes N=34757 (92.70%) | p-value |
|---|---|---|---|
| **Age** | 61.18 (14.65) | 29.58 (23.37) | <.0001 |
| **Glucose** | 159.00 (68.99) | 98.68 (17.43) | <.0001 |
| **Mercury** | 1.48 (2.37) | 1.19 (2.03) | <.0001 |
| **Lead** | 1.76 (1.55) | 1.52 (1.63) | <.0001 |
| **Cadmium** | 0.50 (0.48) | 0.40 (0.53) | <.0001 |
| **BMI** | 32.17 (7.66) | 24.74 (7.30) | <.0001 |
| **Hemoglobin A1C (continuous)** | 7.40 (1.81) | 5.40 (0.57) | <.0001 |
| **Cotinine** | 47.42 (118.90) | 39.82 (106.6) | 0.0008 |
| **Creatinine** | 113.3 (69.28) | 127.9 (80.66) | <.0001 |
| **Urinary Cadmium** | 0.29 (0.41) | 0.46 (0.56) | <.0001 |
| **Sex** | | | 0.9800 |
| Male | 1363 (49.78%) | 17311 (49.81%) | |
| Female | 1375 (50.22%) | 17446 (50.19%) | |
| **Hemoglobin A1C Levels (categorical)** | | | <.0001 |
| Normal | 496 (18.12%) | 29643 (85.29%) | |
| Prediabetes | 637 (23.27%) | 4653 (13.39%) | |
| Diabetes | 1605 (58.62%) | 461 (1.33%) | |
| **Household Income** | | | <.0001 |
| 0 to $24,999 | 835 (42.82%) | 7625 (32.67%) | |
| $25,000 to $64,999 | 740 (37.95%) | 8676 (37.18%) | |
| $65,000 and Over | 375 (19.23%) | 7037 (30.15%) | |
| **Level of Education** | | | <.0001 |
| Less than High School | 550 (20.46%) | 2047 (10.98%) | |
| High School, no diploma | 534 (19.87%) | 2885 (15.47%) | |
| High School w/ diploma, GED | 605 (22.51%) | 4325 (23.20%) | |
| Education Past High School | 999 (37.17%) | 9387 (50.35%) | |
| **Race** | | | <.0001 |
| Mexican American | 474 (17.31%) | 7417 (21.34%) | |
| Other Hispanic | 257 (9.39%) | 3207 (9.23%) | |
| White, Non-Hispanic | 987 (36.05%) | 13203 (37.99%) | |
| Black, Non-Hispanic | 835 (30.50%) | 8078 (23.24%) | |
| Other | 185 (6.76%) | 2852 (8.21%) | |

**Table 3: Weighted Logistic Regression Analysis Identifying Associations between Predictor Variables and Diabetes Status – Questionnaire, N = 20,724**

| Predictor variable | Regression Coefficient (SE) | Wald Chi-Square | P-Value | Odds Ratio |
|---|---|---|---|---|
| **Continuous** | | | | |
| **Age** | 0.0761 (0.00295) | 666.7749 | <0.0001 | 1.079 (1.073, 1.085) |
| **BMI** | 0.0911 (0.00531) | 294.3308 | <0.0001 | 1.095 (1.084, 1.107) |
| **Cotinine** | 0.00106 (0.000332) | 10.2434 | 0.0014 | 1.001 (1.000, 1.002) |
| **Categorical** | | | | |
| **Cadmium (ref= 1st quintile)** | | | | |
| Second Quintile | -0.2504 (0.3246) | 0.5949 | 0.4405 | 0.778 (0.412, 1.471) |
| Third Quintile | -0.1453 (0.1357) | 1.1470 | 0.2842 | 0.865 (0.663, 1.128) |
| Fourth Quintile | -0.2435 (0.1129) | 4.6505 | 0.0310 | 0.784 (0.623, 0.978) |
| Fifth Quintile[1] | -0.1918 (0.1574) | 1.4851 | 0.2230 | 0.825 (0.606, 1.124) |
| **Lead (ref=1st quintile)** | | | | |
| Second Quintile | -0.1251 (0.1651) | 0.5742 | 0.4486 | 0.882 (0.639, 1.219) |
| Third Quintile | -0.7196 (0.1289) | 31.1555 | <0.0001 | 0.487 (0.378, 0.627) |
| Fourth Quintile | -0.9874 (0.1632) | 36.5991 | <0.0001 | 0.373 (0.271, 0.513) |
| Fifth Quintile[2] | -1.2059 (0.1648) | 53.5122 | <0.0001 | 0.299 (0.217, 0.414) |
| **Mercury (ref=1st quintile)** | | | | |
| Second Quintile | -0.2169 (0.1136) | 3.6464 | 0.0562 | 0.805 (0.644, 1.006) |
| Third Quintile | -0.2933 (0.1494) | 3.8543 | 0.0496 | 0.746 (0.556, 1.000) |
| Fourth Quintile | -0.3803 (0.1231) | 9.5425 | 0.0020 | 0.684 (0.537, 0.870) |
| Fifth Quintile[3] | -0.4188 (0.1386) | 9.1282 | 0.0025 | 0.658 (0.501, 0.863) |
| **Sex (ref= female)** | 0.4908 (0.0916) | 28.7104 | <0.0001 | 1.634 (1.365, 1.955) |
| **Income (ref= $25,000 to $64,999 category)** | | | | |
| 0 to $24,999 | 0.2449 (0.0800) | 9.3618 | 0.0022 | 1.277 (1.092, 1.494) |
| $65,000 or more | -0.2734 (0.1025) | 7.1128 | 0.0077 | 0.761 (0.622, 0.930) |
| **Race (ref = white, Non-Hispanic)** | | | | |
| Mexican American | 0.6636 (0.1104) | 36.1631 | <0.0001 | 1.942 (1.564, 2.411) |
| Other Hispanic | 0.4668 (0.1227) | 14.4828 | 0.0001 | 1.595 (1.254, 2.028) |
| Black, Non-Hispanic | 0.8135 (0.0985) | 68.1554 | <0.0001 | 2.256 (1.860, 2.736) |
| Other | 0.9847 (0.1416) | 48.3422 | <0.0001 | 2.677 (2.028, 3.534) |

[1] P-Value for cadmium test for trend, based on log(cadmium): 0.3950

[2] P-Value for lead test for trend, based on log(lead): <0.0001

[3] P-Value for mercury test for trend, based on log(mercury): 0.0114

**Table 4: Weighted Logistic Regression Analysis Identifying Associations between Predictor Variables and High Hemoglobin A1C[4] , N=21,031**

| Predictor variable | Regression Coefficient (SE) | Wald Chi-Square | P-Value | Odds Ratio |
|---|---|---|---|---|
| **Continuous** | | | | |
| **Age** | 0.0753 (0.00307) | 600.8480 | <0.0001 | 1.078 (1.072, 1.085) |
| **BMI** | 0.1029 (0.00463) | 492.9238 | <0.0001 | 1.108 (1.098, 1.118) |
| **Cotinine** | 0.00150 (0.000384) | 29.4374 | <0.0001 | 1.001 (1.001, 1.002) |
| **Categorical** | | | | |
| **Cadmium (ref= 1st quintile)** | | | | |
| Second Quintile | 0.0369 (0.3263) | 0.0128 | 0.9099 | 1.038 (0.547, 1.967) |
| Third Quintile | 0.0269 (0.1280) | 0.0443 | 0.8333 | 1.027 (0.799, 1.320) |
| Fourth Quintile | -0.0078 (0.1365) | 0.0033 | 0.9543 | 0.992 (0.759, 1.297) |
| Fifth Quintile[5] | 0.0970 (0.1496) | 0.4203 | 0.5168 | 1.102 (0.822, 1.477) |
| **Lead (ref=1st quintile)** | | | | |
| Second Quintile | -0.0396 (0.1682) | 0.0555 | 0.8138 | 0.961 (0.691, 1.336) |
| Third Quintile | -0.7504 (0.1496) | 25.1557 | <0.0001 | 0.472 (0.352, 0.633) |
| Fourth Quintile | -0.8425 (0.1776) | 22.5034 | <0.0001 | 0.431 (0.304, 0.610) |
| Fifth Quintile[6] | -1.3668 (0.1912) | 51.0911 | <0.0001 | 0.255 (0.175, 0.371) |
| **Mercury (ref=1st quintile)** | | | | |
| Second Quintile | -0.3195 (0.1259) | 6.4430 | 0.0111 | 0.726 (0.568, 0.930) |
| Third Quintile | -0.4459 (0.1562) | 8.1516 | 0.0043 | 0.640 (0.471, 0.870) |
| Fourth Quintile | -0.4360 (0.1346) | 10.4983 | 0.0012 | 0.647 (0.497, 0.842) |
| Fifth Quintile[7] | -0.3725 (0.1610) | 5.3521 | 0.0207 | 0.689 (0.503, 0.945) |
| **Sex (ref= female)** | 0.6943 (0.0834) | 69.3722 | <0.0001 | 2.002 (1.700, 2.358) |
| **Income (ref= $25,000 to $64,999 category)** | | | | |
| 0 t0 $24,999 | 0.1424 (0.0890) | 2.5622 | 0.1094 | 1.153 (0.969, 1.373) |
| $65,000 or more | -0.1494 (0.1011) | 2.1823 | 0.1396 | 0.861 (0.706, 1.050) |
| **Race (ref = white, Non-Hispanic)** | | | | |
| Mexican American | 1.0888 (0.1225) | 79.0019 | <0.0001 | 2.971 (2.337, 3.777) |
| Other Hispanic | 0.7364 (0.1328) | 30.7663 | <0.0001 | 2.088 (1.610, 2.709) |
| Black, Non-Hispanic | 0.9060 (0.1161) | 60.9197 | <0.0001 | 2.474 (1.972, 3.106) |
| Other | 1.2678 (0.1627) | 60.7086 | <0.0001 | 3.553 (2.583, 4.888) |

[4] Cutpoint used to classify participant as diabetic: 6.5% hemoglobin A1C

[5] P-Value for cadmium test for trend, based on log(cadmium): 0.3338

[6] P-Value for lead test for trend, based on log(lead): <0.0001

[7] P-Value for mercury test for trend, based on log(mercury): 0.1409

**Table 5: Weighted Logistic Regression Analysis Identifying Associations between Predictor Variable (Urinary Cadmium) and Diabetes Status – Questionnaire, N = 6,509**

| Predictor variable | Regression Coefficient (SE) | Wald Chi-Square | P-Value | Odds Ratio |
|---|---|---|---|---|
| **Continuous** | | | | |
| **Age** | 0.0506 (0.00415) | 148.4397 | <0.0001 | 1.052 (1.043, 1.060) |
| **BMI** | 0.1013 (0.0105) | 93.1087 | <0.0001 | 1.107 (1.084, 1.130) |
| **Cotinine** | -0.00027 (0.000552) | 0.2448 | 0.6208 | 1.000 (0.999, 1.001) |
| **Creatinine** | -0.00375 (0.00154) | 5.9308 | 0.0149 | 0.996 (0.993, 0.999) |
| **Categorical** | | | | |
| **Urinary Cadmium (ref= 1st quintile)** | | | | |
| Second Quintile | -0.00140 (0.3352) | 0.0000 | 0.9967 | 0.999 (0.518, 1.926) |
| Third Quintile | 0.1219 (0.3045) | 0.1603 | 0.6889 | 1.130 (0.622, 2.052) |
| Fourth Quintile | 0.3483 (0.3213) | 1.1750 | 0.2784 | 1.417 (0.755, 2.659) |
| Fifth Quintile[8] | 0.2140 (0.3391) | 0.3983 | 0.5280 | 1.239 (0.637, 2.408) |
| **Sex (ref= female)** | 0.3360 (0.1726) | 3.7887 | 0.0516 | 1.399 (0.998, 1.963) |
| **Income (ref= $25,000 to $64,999 category)** | | | | |
| 0 to $24,999 | 0.3914 (0.1606) | 5.9389 | 0.0148 | 1.479 (1.080, 2.026) |
| $65,000 or more | -0.1913 (0.1921) | 0.9917 | 0.3193 | 0.826 (0.567, 1.203) |
| **Race (ref = white, Non-Hispanic)** | | | | |
| Mexican American | 0.4786 (0.1990) | 5.7821 | 0.0162 | 1.614 (1.093, 2.384) |
| Other Hispanic | 0.2114 (0.1861) | 1.2894 | 0.2562 | 1.235 (0.858, 1.779) |
| Black, Non-Hispanic | 0.4988 (0.1509) | 10.9323 | 0.0009 | 1.647 (1.225, 2.213) |
| Other | 0.5060 (0.2223) | 5.1801 | 0.0228 | 1.659 (1.073, 2.564) |

[8] P-Value for urinary cadmium test for trend, based on log(urinary cadmium): 0.2370

**Table 6: Weighted Logistic Regression Analysis Identifying Associations between Predictor Variable (Urinary Cadmium) and High Hemoglobin A1C[9], N = 6,605**

| Predictor variable | Regression Coefficient (SE) | Wald Chi-Square | P-Value | Odds Ratio |
|---|---|---|---|---|
| **Continuous** | | | | |
| **Age** | 0.0554 (0.00493) | 126.3672 | <0.0001 | 1.057 (1.047, 1.067) |
| **BMI** | 0.1132 (0.0105) | 116.7547 | <0.0001 | 1.120 (1.097, 1.143) |
| **Cotinine** | -0.00023 (0.000503) | 0.2062 | 0.6498 | 1.000 (0.999, 1.001) |
| **Creatinine** | -0.00425 (0.00159) | 7.1553 | 0.0075 | 0.996 (0.993, 0.999) |
| **Categorical** | | | | |
| **Urinary Cadmium (ref= 1st quintile)** | | | | |
| Second Quintile | 0.0156(0.3392) | 0.0021 | 0.9633 | 1.016 (0.522, 1.975) |
| Third Quintile | 0.2883 (0.2610) | 1.2199 | 0.2694 | 1.334 (0.800, 2.225) |
| Fourth Quintile | 0.4483 (0.3436) | 1.7026 | 0.1919 | 1.566 (0.798, 3.070) |
| Fifth Quintile[10] | 0.4399 (0.3708) | 1.4075 | 0.2355 | 1.553 (0.751, 3.211) |
| **Sex (ref= female)** | 0.6030 (0.1910) | 9.9635 | 0.0016 | 1.828 (1.257, 2.658) |
| **Income (ref= $25,000 to $64,999 category)** | | | | |
| 0 to $24,999 | 0.3976 (0.1422) | 7.8218 | 0.0052 | 1.488 (1.126, 1.966) |
| $65,000 or more | -0.0167 (0.1841) | 0.0083 | 0.9275 | 0.983 (0.686, 1.411) |
| **Race (ref = white, Non-Hispanic)** | | | | |
| Mexican American | 1.0093 (0.2176) | 21.5147 | <0.0001 | 2.744 (1.791, 4.203) |
| Other Hispanic | 0.6841 (0.2395) | 8.1601 | 0.0043 | 1.982 (1.240, 3.169) |
| Black, Non-Hispanic | 0.6848 (0.1964) | 12.1547 | 0.0005 | 1.983 (1.350, 2.915) |
| Other | 1.0035 (0.2932) | 11.7133 | 0.0006 | 2.728 (1.535, 4.846) |

[9] Cutpoint used to classify participant as diabetic: 6.5% hemoglobin A1C

[10] P-Value for urinary cadmium test for trend, based on log(urinary cadmium): 0.0302

**Table 7. Weighted Multiple Linear Regression Analysis Identifying Associations between Predictor Variables and Continuous, Log Transformed Hemoglobin A1C (%)[11], N = 17226**

| Predictor variable | Regression Coefficient | Standard Error | P-value |
|---|---|---|---|
| **Continuous[12]** | | | |
| Cadmium | 0.0028672 | 0.00214493 | 0.1875 |
| Lead | -0.0174001 | 0.00228401 | <.0001 |
| Mercury | -0.0059572 | 0.00138056 | <.0001 |
| Cotinine | 0.000485 | 0.00001634 | 0.0046 |
| BMI | 0.0036686 | 0.0002100 | <.0001 |
| Age | 0.0027426 | 0.0000980 | <.0001 |
| **Categorica**l | | | |
| Sex(ref=female) | 0.017242 | 0.00249304 | <.0001 |
| Race (ref=Other) | | | |
| Mexican American | -0.0128669 | 0.00669175 | 0.0603 |
| Black, Non-Hispanic | -0.0070627 | 0.00752477 | 0.3525 |
| Other Hispanic | -0.0215085 | 0.00691893 | 0.0031 |
| White, Non-Hispanic | -0.0480486 | 0.00618719 | <.0001 |
| Income (ref=$65000 or more) | | | |
| 0 to $24,999 | 0.0158905 | 0.00292760 | <.0001 |
| $25,000 to $64,499 | 0.0062367 | 0.00322029 | 0.0586 |

[11] R- Square of log transformed data= 0.2194; R-square of untransformed data = 0.1740
[12] The hemoglobin A1C and the predictor variables cadmium, lead, and mercury were log transformed

**Table 8. Weighted Multiple Linear Regression Analysis Identifying Associations between Predictor Variables (Urinary Cadmium) and Continuous, Log Transformed Hemoglobin A1C (%)[13], N = 5715**

| Predictor variable | Regression Coefficient | Standard Error | P-value |
|---|---|---|---|
| **Continuous** | | | |
| Urinary Cadmium[14] | 0.0027121 | 0.0027769 | 0.3335 |
| BMI | 0.0040393 | 0.0003657 | <.0001 |
| Age | 0.0021578 | 0.00013331 | <.0001 |
| Cotinine | 0.0000126 | 0.00001299 | 0.3365 |
| Creatinine | -0.0000682 | 0.00003420 | 0.0517 |
| **Categorica**l | | | |
| Sex(ref=female) | 0.0153192 | 0.00385458 | 0.0002 |
| Race (ref=Other) | | | |
| Mexican American | -0.0018073 | 0.00922098 | 0.8454 |
| Black, Non-Hispanic | -0.0012491 | 0.00708741 | 0.8608 |
| Other Hispanic | -0.0133623 | 0.00773119 | 0.0902 |
| White, Non-Hispanic | -0.0333907 | 0.00583935 | <.0001 |
| Income (ref=$65000 or more) | | | |
| 0 to $24,999 | 0.0194823 | 0.00513829 | 0.0004 |
| $25,000 to $64,499 | 0.0043465 | 0.00430420 | 0.3175 |

[13] R-Square for log transformed data = 0.2151; R- Square for log untranformed= 0.1788
[14] The predictor variable urinary cadmium and hemoglobin A1C were log transformed

**Table 9: Weighted Logistic Regression Analysis Identifying Associations between Predictor Variable (Urinary Cadmium) and High Hemoglobin A1C[15], N = 6,605**

| Predictor variable | Intercept Estimate (SE) | Wald Chi-Square | P-Value | Odds Ratio |
|---|---|---|---|---|
| **Continuous** | | | | |
| **Urinary Cadmium[16]** | 0.2733 (0.1261) | 4.6976 | 0.0302 | 1.314 (1.026, 1.683) |
| **Age** | 0.0530 (0.00525) | 101.9226 | <0.0001 | 1.054 (1.044, 1.065) |
| **BMI** | 0.1144 (0.0104) | 121.8145 | <0.0001 | 1.121 (1.099, 1.144) |
| **Cotinine** | -0.00047 (0.000509) | 0.8597 | 0.3538 | 1.000 (0.999, 1.001) |
| **Creatinine** | -0.00524 (0.00159) | 10.8274 | 0.0010 | 0.995 (0.992, 0.998) |
| **Categorical** | | | | |
| **Sex (ref= female)** | 0.6511 (0.1871) | 12.1151 | 0.0005 | 1.918 (1.329, 2.767) |
| **Income (ref= $25,000 to $64,999 category)** | | | | |
| 0 to $24,999 | 0.3875 (0.1397) | 7.6971 | 0.0055 | 1.473 (1.120, 1.937) |
| $65,000 or more | -0.0154 (0.1856) | 0.0069 | 0.9340 | 0.985 (0.684, 1.417) |
| **Race (ref = white, Non-Hispanic)** | | | | |
| Mexican American | 0.9858 (0.2219) | 19.7351 | <0.0001 | 2.680 (1.735, 4.140) |
| Other Hispanic | 0.6707 (0.2364) | 8.0482 | 0.0046 | 1.956 (1.230, 3.108) |
| Black, Non-Hispanic | 0.6839 (0.1988) | 11.8355 | 0.0006 | 1.982 (1.342, 2.926) |
| Other | 0.9488 (0.2859) | 11.0146 | 0.0009 | 2.583 (1.475, 4.523) |

[15] Cutpoint used to classify participant as diabetic: 6.5% hemoglobin A1C
[16] The predictor variable urinary cadmium was log transformed