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Secular Trends in the Association between Obesity and Hypertension among Adults in the United States, 1999-2014

Short Title: Trends in the Association between Obesity and Hypertension

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Keywords: blood pressure; chronic disease; temporal trends; morbidity; weight status

Significance of the Study

This novel study evaluates whether the magnitude of association between obesity and hypertension has changed over the last 15-years.

Abstract:

Objective: To examine the secular trends in the association between obesity and hypertension among American adults between 1999 and 2014. **Methods**: Data from the 1999-2014 National Health and Nutrition Examination Survey (eight survey cycles) were used. Obesity was determined from measured body mass index, with hypertension assessed from measured blood pressure and self-reported medication use. Meta-regression was used to examine the linear, quadratic, and cubic trends of the relationship between the observed odds ratio effect sizes (obesity and hypertension) and the NHANES cycles (year) using a random-effects model. **Results**: Across the years of 1999 to 2014, there was a significant, positive linear trend (p = 0.006) in the association between overweight/obesity and hypertension. **Conclusion**: Our findings suggest that the association between overweight/obesity and hypertension is becoming stronger over time. Continued surveillance of temporal changes associated with obesity and hypertension is necessary to monitor how such changes may underlie changes in the risk for chronic disease.

Keywords: blood pressure; chronic disease; temporal trends; morbidity; weight status

Abbreviations

BMI, Body Mass Index
BP, Blood Pressure
NHANES, National Health and Nutrition Examination Survey

Introduction

Obesity is becoming an "epidemic" that plagues many parts of the industrialized world, contributing to a global health and economic burden (Hall, Crook, Jones, Wofford, & Dubbert, 2002; Mark, Correia, Morgan, Shaffer, & Haynes, 1999). Recent estimates suggest that obesity affects 36.5% of all adults in the United States (Ogden, Carroll, Fryar, & Flegal, 2015). Excess weight is associated with various negative effects on health outcomes such as cardiovascular disease (Kenchaiah et al., 2002; Lavie, Milani, & Ventura, 2009), hypertension (Krauss, Winston, Fletcher, & Grundy, 1998), diabetes (Gregg, Cheng, Narayan, Thompson, & Williamson, 2007; Leibson et al., 2001), cancer (Calle, Rodriguez, Walker-Thurmond, & Thun, 2003; Renehan, Tyson, Egger, Heller, & Zwahlen, 2008), and early mortality (Calle et al., 2003; Calle, Thun, Petrelli, Rodriguez, & Heath Jr, 1999).

Between 2015 and 2016, the overall prevalence of hypertension was 29% and was higher among non-Hispanic black (40.3%) than among non-Hispanic white (27.8%), non-Hispanic Asian (25.0%), or Hispanic (27.8%) adults (Fryar, Ostchega, Hales, Zhang, & Kruszon-Moran, 2017). Hypertension is a well-established risk factor for stroke (Kannel et al., 1981), kidney disease (Jafar et al., 2003), and mortality (Garland, Barrett-Connor, Suarez, & Criqui, 1983). A diagnosis of hypertension is warranted for individuals with a systolic blood pressure (BP) greater than 130 mmHg, a diastolic BP greater than 80 mmHg, or taking an antihypertensive medication (Muntner et al., 2018).

Moreover, overweight and obesity are associated with hypertension (Chiang, Perlman, & Epstein, 1969). According to previous research, obese and hypertensive patients report common risk factor symptomology, such as insulin resistance and/or type 2 diabetes (DeFronzo & Ferrannini, 1991), hyperinsulinemia (Masuo, Mikami, Ogihara, & Tuck, 2000), systemic hemodynamic (Hall, Brands, Dixon, & Smith, 1993), chronic kidney disease (Hall, 2003), and obstructive sleep apnea. (Phillips et al., 1999). Therefore, the synchronous deleterious effects of obesity and hypertension, in combination, may effectively contribute to increasing health care expenditures (Condliffe, Link, Parasuraman, & Pollack, 2013) and early mortality (Kurukulasuriya, Stas, Lastra, Manrique, & Sowers, 2011).

A comprehensive understanding of secular trends in the association between obesity and hypertension is necessary as public health educators, clinicians and professionals attempt to demarcate time-sensitive changes in the distribution of health-influencing factors over time. Tracking potential temporal trends are useful for healthy policy reform, and national and local resource allocation to epidemiological research and disease prevention. Additionally, evaluating secular trends in the association between weight status and hypertension will provide useful information as to the acceptability and utility of pooling data from multiple time periods (e.g. different survey years) when examining the association between weight status and hypertension, or investigating factors that influence this relationship. Therefore, the main purpose of this study was to evaluate potential secular trends in the relationship between weight status and hypertension among American adults, which, to our knowledge, has yet to be examined.

Methods

Study Design

Data were extracted from eight cycles of the 1999-2014 National Health and Nutrition Examination Survey (NHANES). Data was released in two-year cycles (e.g., 1999-2000, 2001-2002). The NHANES is an ongoing survey conducted by the Centers for Disease Control and Prevention that uses a representative sample of non-institutionalized United States civilians selected by a complex, multistage, stratified, clustered probability design. The multistage design includes the following four stages: 1) identification of counties; 2) identification of segments (city blocks); 3) random selection of households within the selected segments; and 4) random selection of individuals within the selected households. Procedures were approved by the review board of the National Center for Health Statistics. All participants provided consent to participate in the study prior to data collection. More details about NHANES methodology and data collection can be found on the NHANES website (http://www.cdc.gov/nchs/nhanes.htm).

Measurement of Weight and Height Status

Participants' weight was measured using a digital weight scale and expressed in kilograms. After the examiner briefly introduced the exam to the participants, the recorder instructed the examinee to look straight at the center of the scale platform towards the recorder. Once the participant was correctly positioned and the reading of the digital measuring device stabilized, the recorder clicked the screen's weighing button to capture the result in the Integrated Survey Information System (ISIS). Participants' height was measured using a digital stadiometer. The participant stood up straight against the backboard with the body weight evenly distributed and both feet flat on the platform. Participants were instructed to stand with their heels together and toes apart. While the participants were correctly positioned and holding the breath, the measurement on the

ISIS screen was taken. Further information on NHANES body measures collection is available on the NHANES website (http://www.cdc.gov/nchs/nhanes.htm). Body mass index (BMI) was calculated as the ratio between weight in kilograms and height in meters squared (kg/m^2). Overweight and obese, respectively, were defined as having a BMI of 25-30 kg/m^2 and ≥30 kg/m^2.

Measurement of Hypertension

Participants were classified as hypertensive, if they were currently taking BP medication or if the average of four measurements of their BP was ≥130/80 mmHg (Muntner et al., 2018). After five minutes of resting quietly in a sitting position and assessing the maximum inflation level, the BP measurements were taken. The BP technicians of NHANES obtained certification in BP measurement through a training program provided by the Shared Care Research and Education Consulting (Ostchega et al., 2003). The program included a didactic section, audio-video practice watching and listening to systolic and diastolic BP sounds, and measuring BP of volunteers concurrently with a certified, gold standard BP instructor.

Statistical Analysis

Using Stata (v. 12), multiple logistic regression was used to evaluate the association between weight status and hypertension (outcome variable) for each of the eight evaluated NHANES cycles (1999-2014). Models were computed for three separate weight status metrics: (1) BMI as a continuous variable; (2) obese vs. not obese; and (3) overweight/obese vs. not overweight/obese). In each model, covariates included age, gender, and race-ethnicity.

Comprehensive Meta-Analysis (CMA) software was used to evaluate the trend in the effect size between weight status and hypertension across the eight NHANES cycles. Specifically, we used a meta-regression to examine the linear, quadratic, and cubic trends of the relationship between the observed odds ratio effect sizes and the NHANES cycles (year) using a random-effects model (under the assumption of between-study heterogeneity). The degree of heterogeneity of the effect sizes was evaluated with the Cochran's *Q*-statistic, while the proportion of variation attributable to between-study heterogeneity was evaluated with I^2 index.

Results

Across the 1999-2014 NHANES cycles, only adults 20+ years of age were included in the analyses. Among those with complete data on the study variables (age, gender, race-ethnicity, BMI, and BP), the total sample size was 38,993. Table 1 displays the study variable characteristics across each cycle. Participants, on average, were similar for each of the evaluated variables across the cycles, with the exception of age and BMI, which slightly increased over time.

Figure 1 displays the results for the association between BMI (continuous) and hypertension. Across the years of 1999 to 2014, the pooled association between BMI and hypertension was statistically significant (OR = 1.09, 95% CI = 1.08-1.09, $p < 0.001$). That is, for every 1 kg/m^2 increase in BMI, adults had a 9% increased odds of being hypertensive. Regarding the trend in the association between BMI and hypertension across the eight NHANES cycles, there were no statistically significant linear trend (unstandardized regression coefficient [*b*] = 0.001, p = 0.081), quadratic trend (p = 0.852), or cubic trend (p = 0.123); however, at the sample level, there was a slight increase in the odds ratio effect sizes across the NHANES cycles (Figure 2). There was moderate evidence of heterogeneity ($Q(7) = 13.59$, $p = 0.058$, $I^2 = 48.50\%$).

Figure 3 displays the results for the association between obesity (vs. not obese) and hypertension. Across the years of 1999 to 2014, the pooled association between obesity and hypertension was statistically significant (OR = 2.51, 95% CI = 2.27-2.76, $p < 0.001$). That is, on average across the cycles, obese individuals had 2.51 times higher odds of being hypertensive when compared to non-obese adults. Regarding the trend in the association between obesity and hypertension across the eight NHANES cycles, there were no statistically significant linear trend ($b = 0.02$, $p = 0.091$), quadratic trend ($p = 0.980$), or cubic trend ($p = 0.261$); however, at the sample level, there was a slight increase in the odds ratio effect sizes across the NHANES cycles (Figure 4). There was moderate heterogeneity in the effect sizes ($Q(7) = 12.91$, $p = 0.074$, $I^2 = 45.79\%$).

Figure 5 displays the results for the association between overweight/obesity (vs. not overweight/obese) and hypertension. Across the years 1999 to 2014, the pooled association between overweight/obesity and hypertension was statistically significant (OR = 2.23, 95% CI = 2.03-2.44, $p < 0.001$). That is, on average across the cycles, overweight/obese individuals had a 2.23 higher odds of being hypertensive when compared to non-overweight/obese adults. Regarding the trend (Figure 6) in the association between overweight/obesity and hypertension across the eight NHANES cycles, there was statistically significant linear trend ($b = 0.02$, $p = 0.006$) indicating a slight increase in the odds ratios across the NHANES cycles. Quadratic trend ($p = 0.972$) and cubic trend ($p = 0.046$) were not statistically significant. There was moderate heterogeneity in the effect sizes ($Q(7) = 13.12$, $p = 0.069$, $I^2 = 46.66\%$).

Given the observed linear trend between the association of overweight/obesity and hypertension, we evaluated whether there were parallel secular trends in the prevalence of overweight/obesity during this same period. Across the 8 respective NHANES cycles, the prevalence of overweight/obesity was 64%, 65%, 66%, 66%, 68%, 69%, 68%, and 70% ($p_{\text{trend}} < 0.001$).

Discussion

Previous studies have demonstrated an association between increased weight status and various deleterious health outcomes (Kenchaiah et al., 2002; Lavie et al., 2009), including hypertension (Krauss et al., 1998). Other work has also evaluated secular trends in weight status alone (Hales, Fryar, Carroll, Freedman, & Ogden, 2018), as well as trends in hypertension status (Rao, 2012). To date, however, no study has evaluated the secular trends of the relationship between weight status and hypertension, which was the purpose of this project. By pooling results from eight NHANES cycles, including a total of 38,993 participants, we found that people with higher BMI, and people who were categorized as overweight or obese, were more likely to be hypertensive. Further, our findings demonstrate that, between 1999 and 2014, the association between overweight/obesity (vs. not overweight/obese) and hypertension among the broader American adult population became stronger.

When evaluated across the years 1999 to 2008, the prevalence of obesity was 33.8% among adults in 2007 to 2008, with similar rates observed between 1999 and 2000 (Flegal, Carroll, Ogden, & Curtin, 2010). According to another study, the prevalence of obesity was 35.5% in adult males and 35.8% in adult females, with no significant change in obesity prevalence over the 12-year period from 1999 through 2010 (Flegal, Carroll, Kit, & Ogden, 2012). Additionally, secular trends in hypertension diagnoses among U.S adults have also been evaluated. When assessed across the years 1999 to 2010, the prevalence of hypertension was 30.5% among men and 28.5% among women. Similar to the aforementioned papers, there was no evidence of changes in the prevalence across the time-period investigated (Guo, He, Zhang, & Walton, 2012). Relatedly, Yoon et al. (Yoon, Fryar, & Carroll, 2015) assessed hypertension prevalence from 2011 to 2014, reporting an average of 29% (30% for men and 28.1% for women) across the four-year assessment period. Taken together, there is little evidence of a secular trend in hypertension among American adults from 1999-2014 (Guo et al., 2012; Yoon et al., 2015).

In the present study, we confirmed the results of other studies demonstrating an association between weight status and hypertension (Cheung et al., 2017; Krauss et al., 1998; Parker et al., 2016; Someya et al., 2018). Adding novelty to the literature, our results suggest that the magnitude of this robust association is increasing over time. Given these findings, data-driven public health initiatives will be able to provide useful information to aid funding and resource allocation, as well as to substantiate proposals for local or national-level public health policy development, implementation and evaluation of intervention efforts to mitigate the ill-effects of increased weight and hypertension.

In conclusion, we observed relatively strong associations between weight status and hypertension. We also observed evidence that the magnitude of association between overweight/obesity and hypertension has been increasing over time. This finding should be taken into account when combining [NHANES] weight status and hypertension data across multiple years, particularly if the research objective is to evaluate the association between obesity and hypertension. Future studies should aim to identify reasons for the increasing magnitude of association between overweight/obesity and hypertension over time. Other work on this topic should evaluate whether there are secular trends in the relationship between determinants (e.g., dietary, environmental) that may influence the obesity-hypertension relationship.

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Table 1. Characteristics of the sample across the eight NHANES cycles.

	NHANES cycle							
	1999-2000	**2001-2002**	**2003-2004**	**2005-2006**	**2007-2008**	**2009-2010**	**2011-2012**	**2013-2014**
N	4234	4520	4337	4466	5358	5731	5008	5339
Age, mean yrs	45.8 (0.4)	45.7 (0.4)	46.0 (0.4)	46.4 (0.7)	46.7 (0.4)	47.0 (0.4)	47.3 (0.8)	47.3 (0.4)
Gender, % female	51.7	51.8	51.2	51.7	51.9	51.6	51.4	51.7
Race-Ethnicity, % white	69.8	73.2	72.6	72.4	69.6	68.4	66.8	65.9
BMI, mean kg/m2	28.0 (0.2)	28.0 (0.2)	28.1 (0.1)	28.4 (0.2)	28.5 (0.1)	28.7 (0.1)	28.7 (0.2)	29.1 (0.2)
SBP, mean mmHg	123.8 (0.7)	123.0 (0.5)	123.1 (0.5)	122.5 (0.4)	121.9 (0.3)	120.7 (0.4)	121.8 (0.6)	121.7 (0.3)
DBP, mean mmHg	72.3 (0.4)	72.1 (0.4)	70.9 (0.3)	70.2 (0.3)	70.7 (0.3)	69.5 (0.6)	71.4 (0.5)	69.8 (0.3)
% Hypertensive	39.5	39.2	40.8	40.1	39.3	39.2	41.4	40.6

BMI, body mass index
DBP, diastolic blood pressure
SBP, systolic blood pressure
Values in parentheses are standard errors

NHANES Cycle	Statistics for each study: Odds ratio	Lower limit	Upper limit	Relative weight
1999-2000	1.077	1.055	1.099	8.33
2001-2002	1.066	1.048	1.084	10.67
2003-2004	1.080	1.061	1.100	9.82
2005-2006	1.090	1.080	1.100	18.56
2007-2008	1.080	1.068	1.092	16.22
2009-2010	1.102	1.086	1.118	12.66
2011-2012	1.078	1.062	1.095	11.95
2013-2014	1.097	1.080	1.114	11.79
	1.085	1.077	1.092	

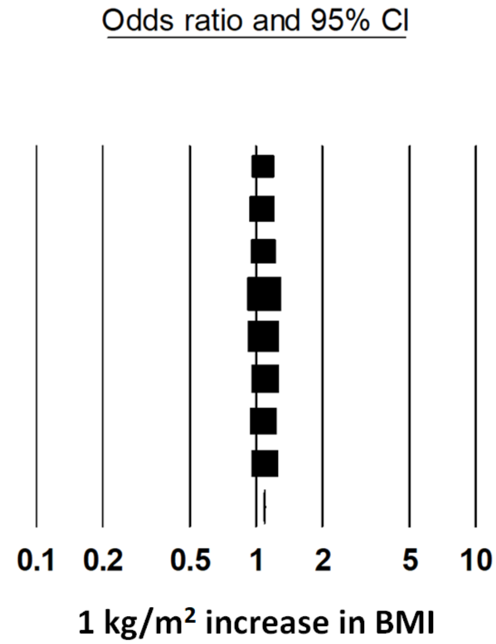

Figure 1. Associations between BMI (continuous) and hypertension across the eight NHANES cycles.

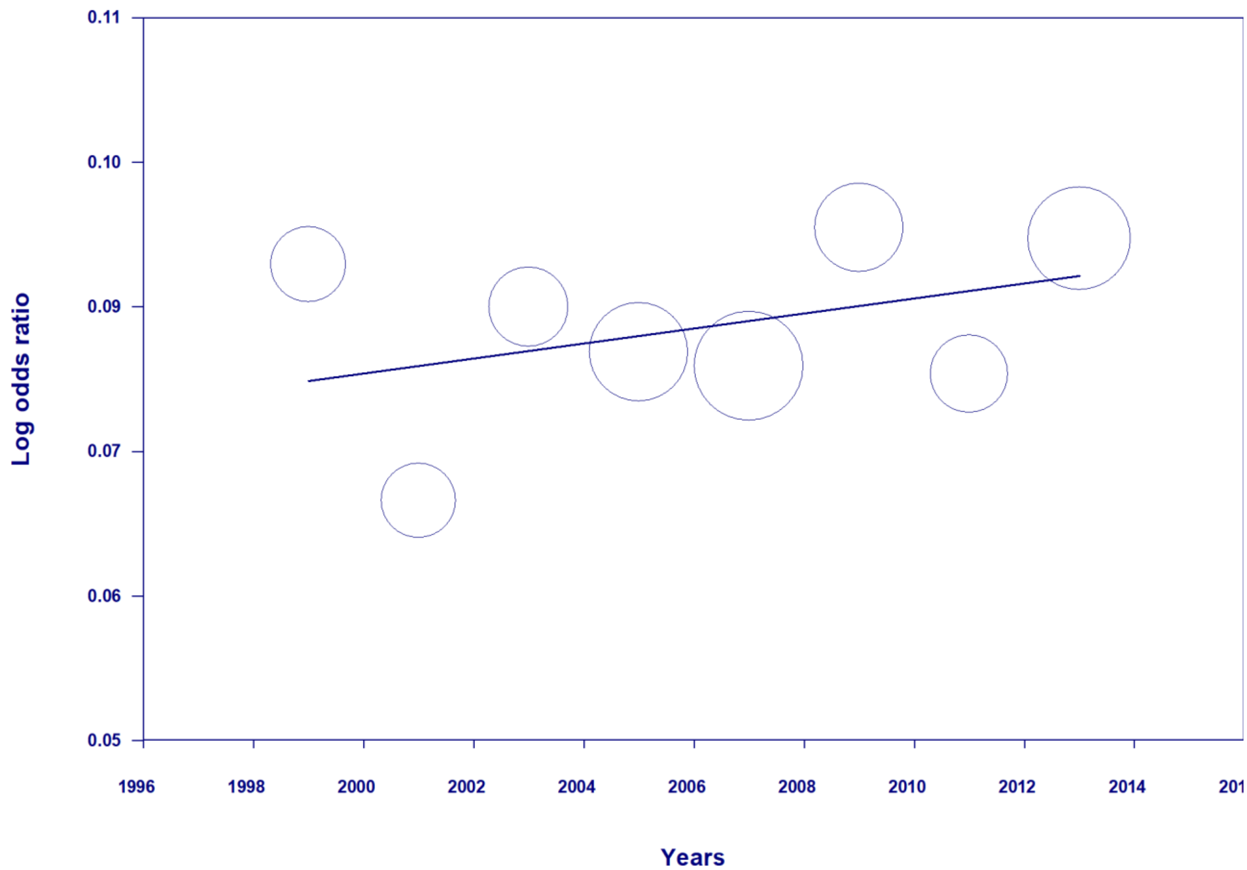

Figure 2. Trend in the association between BMI (continuous) and hypertension across the eight NHANES cycles.

NHANES Cycle	Statistics for each study			Relative weight
	Odds ratio	Lower limit	Upper limit	
1999-2000	2.387	1.878	3.034	10.32
2001-2002	2.127	1.726	2.621	12.16
2003-2004	2.229	1.798	2.763	11.79
2005-2006	2.615	2.196	3.114	14.61
2007-2008	2.350	1.951	2.830	13.74
2009-2010	3.237	2.672	3.922	13.31
2011-2012	2.328	1.854	2.923	11.00
2013-2014	2.812	2.313	3.419	13.07
	2.505	2.272	2.762	

Odds ratio and 95% CI

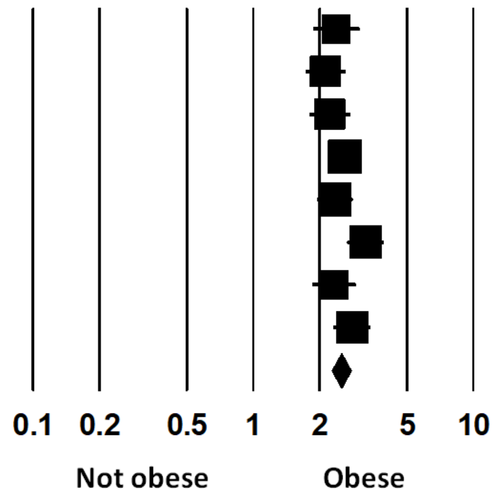

Figure 3. Association between obesity (vs. not) and hypertension across the eight NHANES cycles.

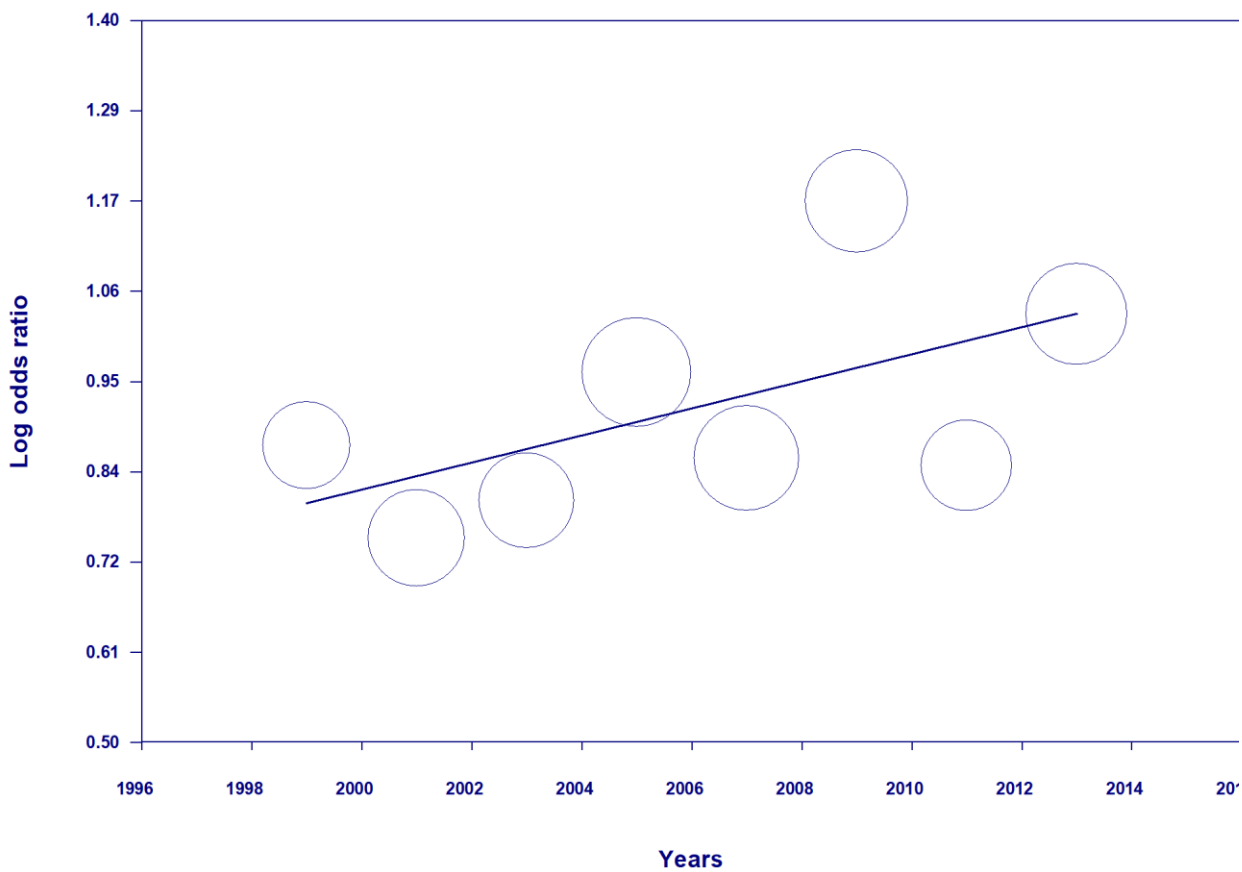

Figure 4. Trend in the association between obesity (vs. not) and hypertension across the eight NHANES cycles.

NHANES Cycle	Statistics for each study: Odds ratio	Lower limit	Upper limit	Relative weight
1999-2000	1.995	1.552	2.564	8.97
2001-2002	1.920	1.678	2.197	17.2
2003-2004	2.322	1.894	2.847	11.6
2005-2006	2.131	1.799	2.525	14.1
2007-2008	2.067	1.716	2.490	12.8
2009-2010	2.744	2.295	3.281	13.4
2011-2012	2.287	1.848	2.830	11.0
2013-2014	2.554	2.053	3.177	10.7
	2.225	2.030	2.439	

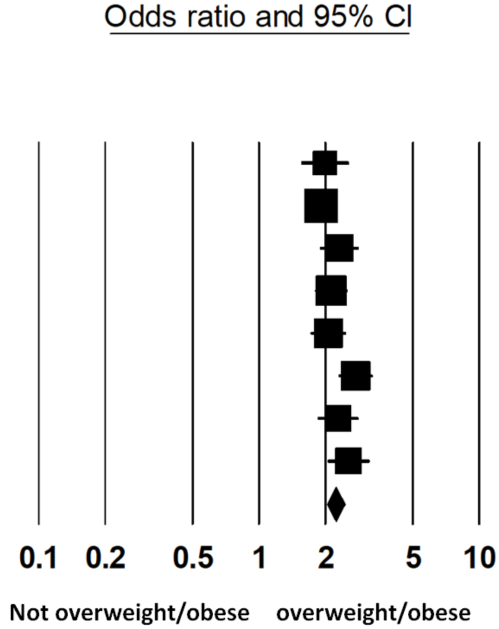

Figure 5. Association between overweight/obesity (vs. not) and hypertension across the eight NHANES cycles.

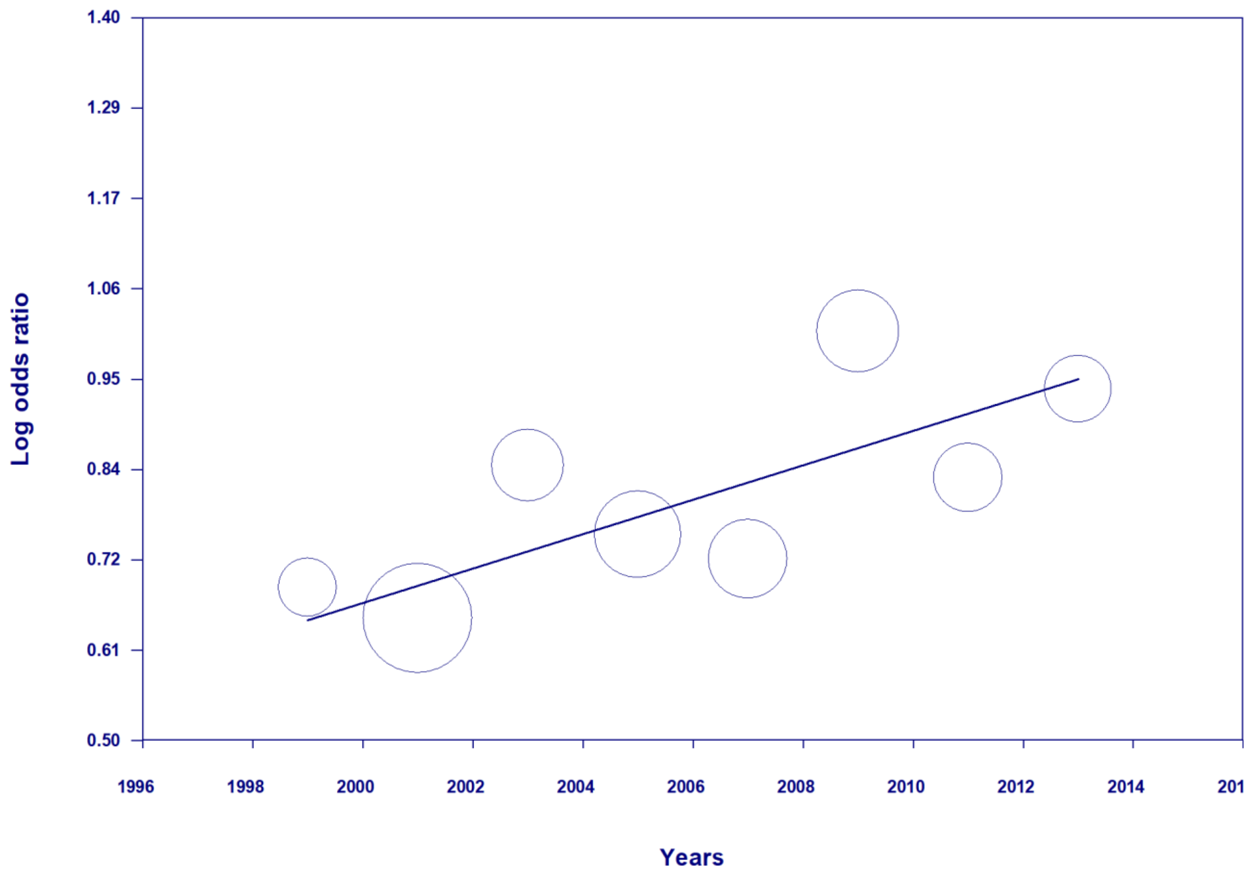

Figure 6. Trend in the association between overweight/obesity (vs. not) and hypertension across the eight NHANES cycles.

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