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Systematic Review

Estimating the Medical Care Costs of Obesity in the United States: Systematic Review, Meta-Analysis, and Empirical Analysis

David D. Kim, MS[1,*], *Anirban Basu, PhD*[1,2]

[1]Department of Health Services, University of Washington, Seattle, WA, USA; [2]The National Bureau of Economic Research, Cambridge, MA, USA

ABSTRACT

Background: The prevalence of adult obesity exceeds 30% in the United States, posing a significant public health concern as well as a substantial financial burden. Although the impact of obesity on medical spending is undeniably significant, the estimated magnitude of the cost of obesity has varied considerably, perhaps driven by different study methodologies. **Objectives:** To document variations in study design and methodology in existing literature and to understand the impact of those variations on the estimated costs of obesity. **Methods:** We conducted a systematic review of the twelve recently published articles that reported costs of obesity and performed a meta-analysis to generate a pooled estimate across those studies. Also, we performed an original analysis to understand the impact of different age groups, statistical models, and confounder adjustment on the magnitude of estimated costs using the nationally representative Medical Expenditure Panel Surveys from 2008-2010. **Results:** We found significant variations among cost estimates in the existing literature. The meta-analysis found that the annual medical spending attributable to an obese individual was $1901 ($1239-$2582) in 2014 USD, accounting for $149.4 billion at the national level. The two most significant drivers of variability in the cost estimates were age groups and adjustment for obesity-related comorbid conditions. **Conclusions:** It would be important to acknowledge variations in the magnitude of the medical cost of obesity driven by different study design and methodology. Researchers and policy-makers need to be cautious on determining appropriate cost estimates according to their scientific and political questions.

Keywords: economic burden, medical care costs, obesity, United States.

Introduction

The prevalence of obesity, which is defined as a body mass index (BMI) of greater than 30, has increased dramatically in the United States since the late 1990s [1]. So much so that recently obesity has been officially recognized as a disease by the American Medical Association, an action that could put more emphasis on the health condition by doctors and insurance companies so as to minimize its adverse effects. Currently, rates of obesity exceed 30% in most sex and adult age groups, whereas its prevalence among children and adolescents, defined as a BMI of more than 95th percentile, has reached 17% [2].

The alarming rates of the high prevalence of obesity have posed a significant public health concern as well as a substantial financial burden on our society because obesity is known to be a risk factor for many chronic diseases, such as type 2 diabetes, cancer, hypertension, asthma, myocardial infarction, stroke, and other conditions–[3,4]. To understand the economic burden of obesity, several studies have attempted to estimate the attributable costs of obesity, following the burden-of-illness literature on other disease areas [5–9]. A previous cost-of-illness study estimated that health care spending attributable to the rising prevalence of obesity has increased by 27% between 1987 and 2001 [10]. In gross terms, the annual medical costs of obesity were estimated to be $40 billion in 2006 [11]. The latest study using an instrumental variable (IV) approach even showed that the estimated medical costs related to obesity could reach $209.7 billion, which is twice higher than the previous estimate, $86 billion [12].

As evidenced by the aforementioned estimates, although the impact of obesity on the medical care spending is undeniably significant, the estimated magnitude of the medical care costs attributable to obesity has varied considerably, perhaps driven by different study methodologies, including data, statistical models, confounder adjustment, and target populations. In this article,

* *Address correspondence to:* David D. Kim, MS, Department of Health Services, School of Public Health, University of Washington, 1959 NE Pacific Street, Box 357660, Seattle, WA 98195.

E-mail: ddkim62@uw.edu.

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we approach these issues systematically with two goals: 1) to conduct a systematic review and meta-analysis of recently published articles that estimated the medical costs associated with obesity between 2008 and 2012 and to document the variations in study methodologies and 2) to demonstrate the importance of study methodologies by performing an original analysis to examine the impact of age group, confounder adjustment, and statistical methods on the cost estimates of obesity through the empirical analysis of a nationally representative US population. Especially, we also examined the impact of obesity-related diseases (ORDs) on the medical costs of obesity to show that most, if not all, of those costs are attributable to ORDs.

We believe that it would be important to recognize significant variations among estimates of obesity-attributable costs in the existing literature and to understand the impact of study methodology on the magnitude of these estimates so that researchers and policymakers are able to determine the appropriate estimate and methods according to their scientific and political questions.

Methods

A Systematic Review and Meta-Analysis

Literature search

We searched the MEDLINE and Cochran database to identify articles related to medical costs of obesity using keywords "obesity AND (cost OR expenditure) AND healthcare)) AND "united states." To account for the unique health care system and the impact of costs attributable to obesity in the United States, we limited the search to studies conducted in the US settings. We initially identified 567 articles from the search, then narrowed down to 16 articles for in-depth reviews. Following the extensive reviews, we excluded three studies that did not provide explicit methods and/or aggregate annual costs per person, in addition to a previously conducted systematic review [13–16]. Finally, we included 12 studies in this study for the systematic review [17–26]. Appendix Figure A in Supplemental Materials found at http://dx.dor.org/10.1016/j.jval.2016.02.008 provides details on search strategies for identifying studies included in this review.

Improve comparability across studies

To improve comparability across heterogeneous studies, we performed appropriate adjustments to convert estimates from each study into annual per-person costs among all obese population (BMI $\geq$ 30).

First, we converted cost estimates to 2014 USD to adjust for the inflation over time using annual average consumer price index for medical care [27]. One study reported the quarter-per-person medical costs, and we annualized the cost estimate [17]. All the 12 studies reported direct medical costs, including the out-of-pocket costs for inpatient, noninpatient (outpatient, emergency room, and other), and prescription drug spending.

Then, we aggregated all BMI-specific estimates into a single composite estimate of costs attributable to all obese individuals. Among the 12 studies, 8 studies defined obesity as a BMI of greater than 30 whereas 4 studies implemented more comprehensive obesity categories, defined as class I obesity (30 $<$ BMI $\leq$ 35), class II obesity (35 $<$ BMI $\leq$ 40), and class III obesity (40 $<$ BMI) [21,22,24,26]. Two of the four studies combined class II and class III obesity into a single category because of the sample size issue [22,26]. To generate comparable cost estimates, we calculated a weighted average among subgroup-specific estimates on the basis of the number of each subgroup reported in each of the four studies.

In addition, three studies estimated sex-specific costs of obesity [18,20,23], and one study provided race (non-Hispanic whites vs. blacks) stratified results [26]. Another study reported both sex and race (non-Hispanic whites vs. blacks) stratified estimates [19]. Based on the sample size of each stratum presented in each study, only the weighted average estimates for aggregating sex and race categories are presented in Table 2.

Evaluating quality of studies

We evaluated the quality of studies on the basis of four criteria: the use of nationally representative samples, longitudinal data sets, analysis of adults of all ages, and appropriate confounding factor adjustments. A previous systematic review also used a similar set of criteria for evaluating cost-of-illness studies of obesity [13].

Meta-analysis

To generate a pooled estimate of medical costs of obesity across different studies, we conducted a meta-analysis using the `metaan` command in STATA 12 (StataCorp., College Station, TX) [28]. The `metaan` command is used to conduct random-effect meta-analysis for one-variable relationship. Because the meta-analysis for one-variable relationship requires both the effect size estimate and the standard error, we were able to include only eight estimates of annual incremental costs of obesity from seven studies (Table 2). Because of the presence of extremely high heterogeneity between studies ($I^2 = 96.61\%$; $\tau^2 = 5.6 \times 10^5$), the random-effect model is used in the final analysis.

Empirical Analysis: The Role of Alternative Statistical Models in Estimating Costs of Obesity

Study data

The medical costs of obesity were estimated using regression analysis and the 2008-2010 Medical Expenditure Panel Surveys (MEPS). The MEPS is a nationally representative survey of the civilian noninstitutionalized population, collecting detailed information on health care expenditures and utilization, health insurance, health status, and sociodemographic factors. Nationally representative estimates were obtained by using MEPS sampling weights.

Variables

As a dependent variable, *medical care costs* (which include costs for office-based visits, hospital outpatient visits, emergency room visits, inpatient hospital stays, prescription drugs, dental visits, and home care) are defined as the sum of direct payments from all parties (out-of-pocket, private insurers, government, and other payers) for care provided during the year. For a primary independent variable, we identified obesity status on the basis of the constructed BMI through self-reported height and measure [29]. (Please note that because of confidentiality concerns and restrictions, the self-reported weight and height variables were not available from the public-access MEPS data sets.) Also, we categorized potential confounding factors into four categories to examine the impact of confounder adjustments on the magnitude of the cost estimates: 1) Demographic factors or cov1 (age, sex, and race/ethnicity), 2) Socioeconomic factors or cov2 (education, household income based on the federal poverty line, smoking status, and marital status), 3) Additional factors or cov3 (census region and insurance status), and 4) comorbidity conditions or cov4. *Comorbidity conditions* are defined as a continuous variable ranging from 0 to 10 by summing up 10 potential health consequences that can be caused be obesity. These conditions, called ORDs, which are defined by the Centers for Disease Control and Prevention, include hypertension, heart diseases (coronary heart disease, angina, myocardial infarction, others), stroke, cancer, diabetes, arthritis, and high cholesterol [30]. In this data set, children or adolescents (age $<$ 18 years) do not have any information on comorbidity conditions and

Table 1 – Characteristics of 12 studies included in this review.

Study	Data	Sample size	Statistical methods*	Obesity class	Target population	Variable adjusted for	Quality evaluation (score out of 4)
Medical care cost of obesity—Annual cost per person (common confounders†)							
Wolf et al. [17], 2008	US PROCEED	1,300	Log-linear	Aggregate	Adults (aged 35–75 y)	(– race/ethnicity, income, marital status) (+ alcohol use, comorbidities, insurance)	2: Longitudinal data, confounder adjustment
Finkelstein et al. [11], 2009	MEPS (2006)	21,877	Two-part (logit-GLM)	Aggregate	All adults (age ≥ 18 y)	(+ census region, insurance status)	3: Nationally representative sample, all adults, confounder adjustment
Cai et al. [20], 2010	MCBS (1991–2000)	5,043	Unadjusted	Aggregate	Adults aged 35–55 y in the period 1971–1975	Unadjusted	1: Nationally representative sample
Finkelstein et al. [21], 2010	MEPS (2006)	8,875	Two-part (logit-GLM)	Obesity class I, II, and III	All adults (age ≥ 18 y) Full-time employees only	(+ age^2, census region, insurance status)	3: Nationally representative sample, all adults, confounder adjustment
Bell et al. [23], 2011	MEPS (2000–2005)	80,516	Two-part (logit-log (Y) OLS)	Aggregate	Children and adults aged 6–85 y	(– smoking, marital status) (+ age^2, age^3, region, insurance status, survey year)	3: Nationally representative sample, all adults, confounder adjustment
Onwudiwe et al. [22], 2011	MCBS (2002)	7,706	One-part GLM	Obesity class I and II/III	Medicare beneficiaries (age ≥ 65 y) Not in HMO plan	(+ insurance status)	2: Nationally representative sample, confounder adjustment
Alley et al. [25], 2012	MCBS (1997–2006)	29,413	One-part GLM	Aggregate	Medicare beneficiaries (age ≥ 65 y)	(+ census region, metropolitan status, mortality variable)	3: Nationally representative sample, all adults, confounder adjustment
Cawley and Meyerhoefer [12], 2012	MEPS (2000–2005)	23,689	IV with two-part (logit-GLM) IV: a weight of biological relative	Aggregate	Adults (aged 20–64 y with biological children aged 11–20 y)	(– income, smoking, marital status) (+ census region, MSA, household composition, survey information, employment status, fixed effects for year, the sex and age of the oldest children)	3: Nationally representative sample, confounder adjustment (IV)
Ma et al. [26], 2012	MEPS (2006)	15,164	Unadjusted	Obesity class I and II/III	All adults (age ≥ 18 y)	Unadjusted	2: Nationally representative sample, all adults
Moriarty et al. [24], 2012	Mayo Clinic Database (2001–2007)	30,529	GEE	Obesity class I, II, and III	Adults (18–65 y) vs. adults (>65 y)	(– education, income) (+ comorbidity conditions for an additional analysis)	3: Longitudinal data, all adults, confounder adjustment

Medical care cost of obesity—Lifetime cost per person (all adjusted for survival)							
Finkelstein et al. [19], 2008	MEPS (2001–2004)	66,161	Two-part model (logit-GLM)	Obesity class I and II/III	All adults (age ≥ 18 y)	(– income) (+ insurance status, census region, population density, age^2, age^3)	3: Nationally representative sample, all adults, confounder adjustment
Yang and Hall [18], 2008	MCBS (1992–2001)	28,906	Two-part model (logit-log (Y) OLS)	Aggregate	Medicare beneficiaries (age ≥ 65 y)	(+ functional status, existing chronic diseases, acute medical events, urban/rural)	2: Nationally representative, confounder adjustment
Cai et al. [20], 2010	MCBS (1991–2000)	5,043	One-part GLM	Aggregate	Adults aged 35–55 y in the period 1971–1975	(– education, income, marital status) (+ time to death)	2: Nationally representative, confounder adjustment

GEE, generalized estimating equation; GLM, generalized linear model; HMO, health maintenance organization; IV, instrumental variable; MCBS, Medicare Current Beneficiary Survey; MEPS, Medical Expenditure Panel Surveys; MSA, Metropolitan statistical area; OLS, ordinary least squares; PROCEED, Prospective Obesity Cohort of Economic Evaluation and Determinants.

* All GLM and GEE models used the log link and the gamma distribution.

† Common confounding covariates: Age, sex, race/ethnicity, education, income, smoking status, and marital status.

smoking status, and only very few individuals reported education (N = 25) and marital status (N = 6).

Study design and data analysis

To study the impact of various study designs, we examined three different aspects of estimating medical costs in a regression analysis: age groups, statistical models, and confounder adjustments. The age groups were 1) children/adolescents (aged 0–17 years), 2) all adults (aged ≥ 18 years), 3) adults aged 18 to 65 years, and 4) older adults (aged ≥65 years). Considering the nature of cost data, such as non-negative observations, a large number of observations at zero, and positive skewness, we examined five different statistical models that have been widely used to estimate the medical costs: 1) linear regression, 2) log-linear model (a simple ordinary least square for ln(y)), 3) one-part log-gamma generalized linear model (GLM), 4) two-part model with a logistic regression and a log-gamma GLM, and 5) extended estimating equation (EEE) that used both a flexible link and a flexible variance function estimated directly from the data to capture the underlying nonlinearity in the data so that it can produce efficient estimates [31–34]. Also, we tested the goodness of fit (GoF) of each statistical model to examine how well the model fits a data set using Pearson correlation, Pregobon's link test, and Hosmer-Lemeshow test. In regard to confounder adjustment, four sets of confounders were studied: 1) Demographic factors (cov1), 2) Demographic + Socioeconomic factors (cov1 + cov2), 3) Demographic + Socioeconomic + Additional factors (cov1 + cov2 + cov3), and 4) All three factors + ORDs (cov1 + cov2 + cov3 + cov4). Using different combinations of the target population, statistical models, and confounder adjustment, we estimated medical care costs of nonobese individuals (so called costs of normal) as well as incremental costs of obesity through recycled predictions to estimate the counterfactual mean costs if all individuals in the data set were suddenly to have obesity while retained all other characteristics as compared with being nonobese for all individuals. We also tested the GoF of five different statistical models with each of four different sets of confounding factors for the sample population of all adults. All standard errors and confidence intervals (CIs) were estimated from 1000 bootstrap replicates.

Results

A Systematic Review and Meta-Analysis

Descriptive results

Among the 12 studies included in this systematic review, 9 studies reported annual medical care costs per person while 2 studies provided lifetime medical care costs per person and 1 study reported both estimates. Six studies used the MEPS database, whereas four studies used the Medicare Current Beneficiary Survey database. The remaining two studies used the Prospective Obesity Cohort of Economic Evaluation and Determinants data set, which is a multinational, observational, prospective Internet-based cohort study and the Mayo clinic employment database, respectively (Table 1).

Quality evaluation

Based on four quality criteria, no studies met all criteria, because all the studies that used a nationally representative data set were not a longitudinal study or vice versa. Among 10 studies that reported annual costs per person, 5 studies were designated as "high-quality (score = 3)" study (Table 1). Because Cawley's study was the only study that estimated medical costs of obesity using the instrumental variable IV approach to account for unobserved

Table 2 – Systematic review—Medical costs of obesity (2014 USD).

Study	Cost of normal*	Cost of obesity*	Incremental cost of obesity*	Year of cost reporting	Note
Medical care cost of obesity—Annual cost per person					
Wolf et al. [17], 2008	$2,541	$6,611	$4,070†	2004	
Finkelstein et al. [11], 2009	$4,087	$5,783	$1,696†	2008	
Cai et al. [20], 2010	$5,750	$13,019	$7,269	2000	Unadjusted
Finkelstein et al. [21], 2010	NA	NA	$1,024	2006	Obese I, medical costs only
			$1,944		Obese II, medical costs only
			$2,215		Obese III, medical costs only
			$1,397†		Aggregate, medical costs only
Bell et al. [23], 2011	$3,629	$5,488	$1,859†	2005	
Onwudiwe et al. [22], 2011	$5,666	$5,578	−$88	2002	Obese I, uncorrected for the height loss
		$6,637	$971		Obese II/III, uncorrected for the height loss
		$5,892	$227†		Aggregate obese, uncorrected for the height loss
Alley et al. [25], 2012	$8,781	$7,338	−$1,443	2006	Annual spending in 1997 converted to 2008 USD
	$157	$191	$34		Expenditures increased per year from 1997 to 2006
Cawley and Meyerhoefer [12], 2012	NA	NA	$877†	2005	Without using the instrumental variable
			$3,665†		With using the instrumental variable
Ma et al. [26], 2012	$4,797	$6,152	$1,356	2006	Obese I, unadjusted
		$8,408	$3,611		Obese II/III, unadjusted
		$7,082	$2,285		Aggregate, unadjusted
Moriarty et al. [24], 2012	NA	NA	$2,278	2007	Obese I, no comorbidity adjustment
			$3,759		Obese II, no comorbidity adjustment
			$6,794		Obese III, no comorbidity adjustment
			$3,302†		Aggregate obese, no comorbidity adjustment
Medical care cost of obesity—Lifetime costs per person (all adjusted for survival)					
Finkelstein et al. [19], 2008	NA	NA	$19,892	2007	From age 20 y, obese I—Discounted lifetime costs
			$28,441		From age 20 y, obese II/III—Discounted lifetime costs
			$23,123		From age 20 y, aggregate—Discounted lifetime costs
			$15,641		From age 65 y, obese I—Discounted lifetime costs
			$24,589		From age 65 y, obese II/III—Discounted lifetime costs
			$19,022		From age 65 y, aggregate—Discounted lifetime costs
Yang and Hall [18], 2008	$288,934	$332,838	$43,904	2001	From age 65 y—Not discounted
Cai et al. [20], 2010	$194,013	$269,628	$75,615	2000	From age 45 y—Not discounted

NA, not applicable/available.

* All costs were converted to 2014 US dollar using Consumer Price Index—Medical Care.

† Represents the cost estimates included in the meta-analysis to calculate the pooled incremental cost of obesity.

confounding factors, the study received an extra score for confounder adjustment criteria [12].

Cost estimates

The annual incremental costs of obesity per person ranged from $227 to $7269 depending on the study designs and research methods. Tables 2 and 3 provide details on different study methodologies and reported cost estimates. From the meta-analysis with the random-effect model, the pooled estimate of annual medical costs of obesity was $1910 (95% CI $1239–$2582). A forest plot from the random-effect model is shown in Figure 1.

Three studies reported the lifetime costs associated with obesity after adjusting for survival. One study estimated the lifetime costs of obesity with a 3% annual discount on the dollar value, resulting in $23,123 from age 20 years and $19,022 from age 65 years [19], whereas another study without using a discount rate reported the lifetime costs of $43,904 from age 65 years [18].

Table 3 – Systematic review—Medical costs of obesity by study methodologies (2014 USD).

Confounding factors		Unadjusted	Demographic factors	Demographic + socioeconomic factors	Demographic + SES + additional factors	All factors + comorbidities
Statistical methods	Age groups					
Linear regression	Children/adolescents					
	All adults (age ≥ 18 y)	$2,285 (Ma et al. [26], 2012)				
	Adults (18–65 y)	$7,269 (Cai et al. [20], 2010)				
	Older adults (age ≥ 65 y)					
Log-linear	Children/adolescents					
	All adults (age ≥ 18 y)					
	Adults (18–65 y)			$4,070 (Wolf, 2008)		
	Older adults (age ≥ 65 y)					
One-part GLM	Children/adolescents					
	All adults (age ≥ 18 y)					
	Adults (18–65 y)					
	Older adults (age ≥ 65 y)				$227 (Onwudiwe, 2011) –$1,443 (Alley, 2012)	
Two-part GLM	Children/adolescents					
	All adults (age ≥ 18 y)				$1,696 (Finkelstein, 2009) $1,359 (Finkelsten, 2010) $1,859 (Bell, 2011)	
	Adults (18–65 y)				$877 (Cawley, 2012)	
	Older adults (age ≥ 65 y)					
Other methods	Children/adolescents					
	All adults (age ≥ 18 y)			$3,302 (Moriarty, 2012)—GEE		
	Adults (18–65 y)				$3,665 (Cawley, 2012)—IV	
	Older adults (age ≥ 65 y)					

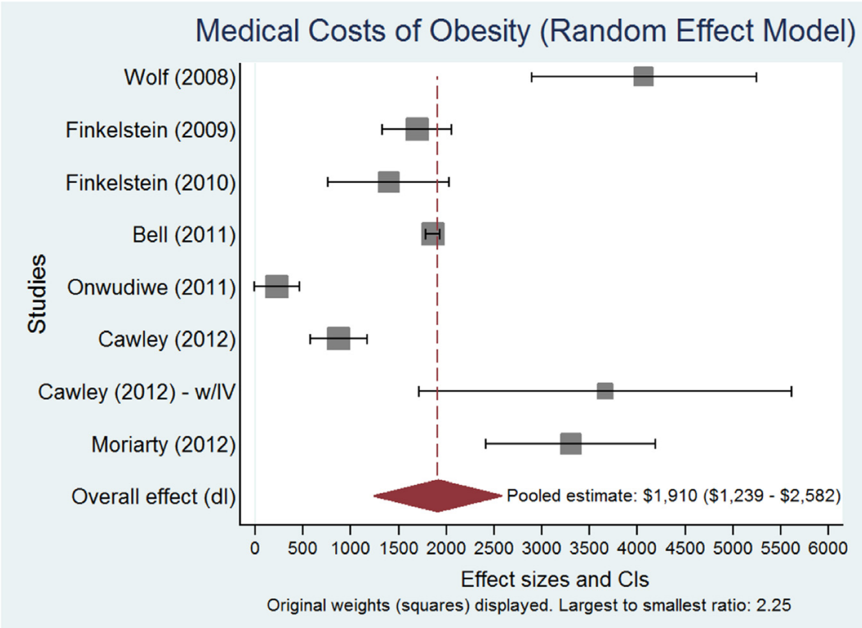


Fig. 1 – Meta-analysis: Medical costs of obesity (random-effect model). CI, confidence interval; IV, instrumental variable.

Stratified results

Among the studies that provided stratified estimates of the medical costs attributable to obesity, the annual costs increased in higher obese categories [21,22,24,26] and the lifetime costs of obesity were also positively associated with an increasing BMI [19]. The magnitude of the annual costs related to obesity was higher among women than among men [18–20,23]. Also, obese blacks were found to spend less medical costs than obese whites, mainly due to more use of relatively inexpensive types of care (office-based visits, outpatient care, medications) rather than more costly ones (inpatient, emergency room) [19,26].

Different study methodology

Among the 10 studies that estimated annual medical care cost attributable to obesity, a two-part model was the most popular method used by four studies. Three of those four studies implemented a logistic regression with a log-gamma GLM [11,12,21], whereas another study used a logit model with a log-linear model [23]. Two studies used a one-part GLM method with a log link and a gamma distribution [22,25]. A generalized estimating equation [24] and a log-linear regression model [17] were used in other two studies, respectively, and the remaining two studies reported unadjusted annual costs of obesity [20,26]. Because each study used distinctive data sets to various study methodologies, it is hard to predict the actual impact of a range of study methodologies on the magnitude of the costs of obesity. However, one study using both a two-part model and an IV approach provided that the effect of obesity on medical care costs was much greater with the IV method than was previously appreciated with the two-part model. The instrument used in the study was the weight of a biological relative [12].

Different confounder adjustment

We defined confounding factors that were widely used to adjust for the causal inference among these studies, including demographic factors, socioeconomic factors, additional factors, and obesity-related comorbidity conditions. However, none of these studies selected the same set of confounding factors. Table 1 presents a significant variability in choosing confounding factors, and the substantial variability poses an essential problem of comparing these estimates directly. A study that examined two models with and without adjusting for comorbidity conditions as a confounding factor found that incremental costs of obesity dropped significantly when adjusted for comorbidities [24].

Estimating Medical Costs of Obesity

With possible combinations of the four age groups, the five statistical models, and the four sets of potential confounders, 80 estimates of costs of normal and incremental costs of obesity were generated with 95% CIs. All possible cost estimates are provided in Table 4.

Characteristics of individuals in the data set

Individual characteristics used in estimating medical costs of obesity are presented in Appendix Table A in Supplemental Materials found at http://dx.dor.org/10.1016/j.jval.2016.02.008. In this analysis, the data set includes 15,176 children and adolescents and 69,382 adults aged 18 years and older, including 10,382 older adults (age $\geq$ 65 years) with existing obesity status. Among the obese, there was a significantly higher proportion of females, blacks, Hispanics, individuals in lower household income level (<125% federal poverty line), only high school or equivalent degree holder, those who were married, individuals with public insurance, and those living in the South region, compared with the nonobese. Also, as expected, individuals with obesity have a higher number of obesity-related comorbidity conditions than do those without obesity.

Effect of different target populations

For children/adolescents, regardless of different statistical models and confounding factor adjustment, there was no significant difference between costs of the nonobese and the obese, except only one scenario with a one-part GLM controlling for all confounding factors available (no comorbidities and smoking) that reported $1085 ($92–$2377) for the incremental costs of obesity for children/adolescents. However, for the adult population, the

Table 4 – Factors affecting costs of normal (nonobese) and incremental costs of obesity.

Confounding factors		Unadjusted			Demographic factors[1]			Demographic + socioeconomic factors[2]			Demographic + SES + additional factors[3]			All factors + comorbidities[4]		
Statistical methods	Age groups	Cost of normal	Incremental cost of obesity	95% CI	Cost of normal	Incremental cost of obesity	95% CI	Cost of normal	Incremental cost of obesity	95% CI	Cost of normal	Incremental cost of obesity	95% CI	Cost of normal	Incremental cost of obesity	95% CI
Linear regression	Children/ adolescents	1,851	−62	(−455 to 333)	1,265	182	(−198 to 563)	1,591	621	(−285 to 1528)	1,580	647	(−269 to 1563)	NA	NA	NA
	All adults (age ≥ 18 y)	4,574	1,766	(1477 to 2056)	4,252	1,411	(1096 to 1689)	4,436	1,453	(1139 to 1738)	4,443	1,406	(1101 to 1700)	4,792	153	(−156 to 456)
	Adults (18–65 y)	3,524	1,795	(1502 to 2088)	3,345	1,283	(995 to 1570)	3,494	1,312	(1006 to 1617)	3,559	1,153	(851 to 1456)	3,855	93	(−211 to 397)
	Older adults (age ≥ 65 y)	9,558	2,290	(1385 to 3195)	9,247	2,898	(1975 to 3820)	9,380	2,747	(1794 to 3701)	9,362	2,717	(1762 to 3673)	9,954	496	(−421 to 1413)
Log-linear	Children/ adolescents	1,975	90	(−413 to 826)	1,640	366	(−178 to 1186)	2,145	1,112	(−67 to 2533)	2,074	1,191	(−36 to 2652)	NA	NA	NA
	All adults (age ≥ 18 y)	5,186	1,562	(1318 to 1823)	5,394	1,375	(1089 to 1705)	5,546	1,412	(1101 to 1753)	5,452	1,261	(950 to 1561)	6,236	61	(−250 to 358)
	Adults (18–65 y)	4,175	1,614	(1372 to 1858)	4,298	1,015	(759 to 1294)	4,407	1,031	(764 to 1312)	4,321	819	(544 to 1086)	4,935	−78	(−347 to 197)
	Older adults (age ≥ 65 y)	9,468	2,283	(1522 to 3012)	9,439	3,528	(2556 to 4456)	9,602	3,431	(2461 to 4371)	9,654	3,378	(2425 to 4354)	10,849	425	(−435 to 1273)
One-part GLM	Children/ adolescents	1,851	−62	(−396 to 349)	1,376	140	(−140 to 532)	1,571	715	(−240 to 1567)	1,556	1,085	(92 to 2377)	NA	NA	NA
	All adults (age ≥ 18 y)	4,574	1,766	(1462 to 2056)	4,279	1,450	(1139 to1720)	4,446	1,506	(1210 to 1822)	4,511	1,397	(1091 to 1665)	5,048	429	(103 to 728)
	Adults (18–65 y)	3,524	1,795	(1509 to 2089)	3,383	1,088	(843 to 1336)	3,517	1,143	(890 to 1407)	3,580	970	(702 to 1216)	4,115	258	(−14 to 535)
	Older adults (age ≥ 65 y)	9,558	2,290	(1415 to 3193)	9,235	3,124	(2090 to 4046)	9,358	2,992	(1918 to 3977)	9,342	2,944	(1858 to 3859)	9,981	600	(−272 to 1496)
Two-part GLM	Children/ adolescents	2,162	−62	(−359 to 455)	1,953	140	(−146 to 653)	2,063	475	(−175 to 1289)	2,066	750	(−2 to 1894)	NA	NA	NA
	All adults (age ≥ 18 y)	5,483	1,834	(1553 to 2170)	5,358	1,524	(1247 to 1803)	5,498	1,578	(1284 to 1848)	5,535	1,481	(1186 to 1754)	5,949	399	(112 to 665)
	Adults (18–65 y)	4,369	1,880	(1581 to 2206)	4,391	1,190	(938 to 1428)	4,528	1,234	(957 to 1467)	4,579	1,070	(813 to 1313)	4,974	269	(8 to 506)
	Older adults (age ≥ 65 y)	9,894	2,328	(1481 to 3280)	9,628	3,191	(2264 to 4187)	9,749	3,060	(2040 to 4017)	9,740	3,014	(1991 to 3993)	10,315	555	(−320 to 1451)

continued on next page

Table 4 – *continued*

Confounding factors		Unadjusted			Demographic factors[1]			Demographic + socioeconomic factors[2]			Demographic + SES + additional factors[3]			All factors + comorbidities[4]		
EEE	Children/ adolescents	1,851	−62	(−376 to 389)	NA	NA	NA	1,593	653	(−33 to 1556)	NA	NA	NA	NA	NA	NA
	All adults (age ≥ 18 y)	4,574	1,766	(1445 to 2042)	4,250	1,346	(1065 to 1604)	4,441	1,356	(1076 to 1644)	4,414	1,343	(1076 to 1621)	4,764	209	(−21 to 434)
	Adults (18–65 y)	3,524	1,795	(1509 to 2089)	3,358	1,135	(904 to 1383)	3,505	1,170	(927 to 1445)	3,492	1,094	(859 to 1359)	3,804	184	(−41 to 398)
	Older adults (age ≥ 65 y)	9,558	2,290	(1415 to 3193)	9,246	2,844	(1819 to 3776)	9,397	2,699	(1427 to 3529)	9,447	2,698	(978 to 4418)	9,973	344	(−387 to 1231)

CI, confidence interval; EEE, extended estimating equation; GEE, generalized estimating equation; GLM, generalized linear model; IV, instrumental variable; NA, not applicable/available.
1. Demographic factors: Age, sex, and race/ethnicity; 2. Socioeconomic factors: Education, household income, smoking status, and marital status; 3. Additional factors: Census region and insurance status; 4. Comorbidities: The presence of 10 obesity-related diseases (0–10)

incremental costs of obesity were significantly higher than for the nonobese. Among adults, in most of the combinations with statistical models and confounding factors, the incremental costs of obesity for older adults (age ≥ 65 years) were significantly higher than those for adults aged 18 to 65 years (Fig. 2 and Table 4). From the EEE model controlling for demographic, socioeconomic, and additional factors (cov1 + cov2 + cov3), the incremental costs of obesity for adults aged 18 to 65 years were reported as $1094 ($859–$1359) while the costs of obesity for older adults were $2668 ($978–$4418).

Effect of different statistical models

Medical care costs attributable to obesity did not differ significantly by using different statistical models, although the GoF tests showed that an EEE model fitted the data most thoroughly, followed by a one-part GLM. For all adults, controlling for demographic and socioeconomic and additional factors (cov1 + cov2 + cov3), the EEE model reported $1343 ($1076–$1621) for the incremental costs of obesity, whereas the estimates ranged from $1261 ($950–$1561) in the log-linear model to $1481 ($1186–$1754) in the two-part GLM (Fig. 2; Table 4). Also, compared with other models, the EEE model provided the most stable estimates over the different sets of confounding factor adjustment, varying only from $1346 with cov1 to $1356 with cov1 + cov2 to $1343 with cov1 + cov2 + cov3.

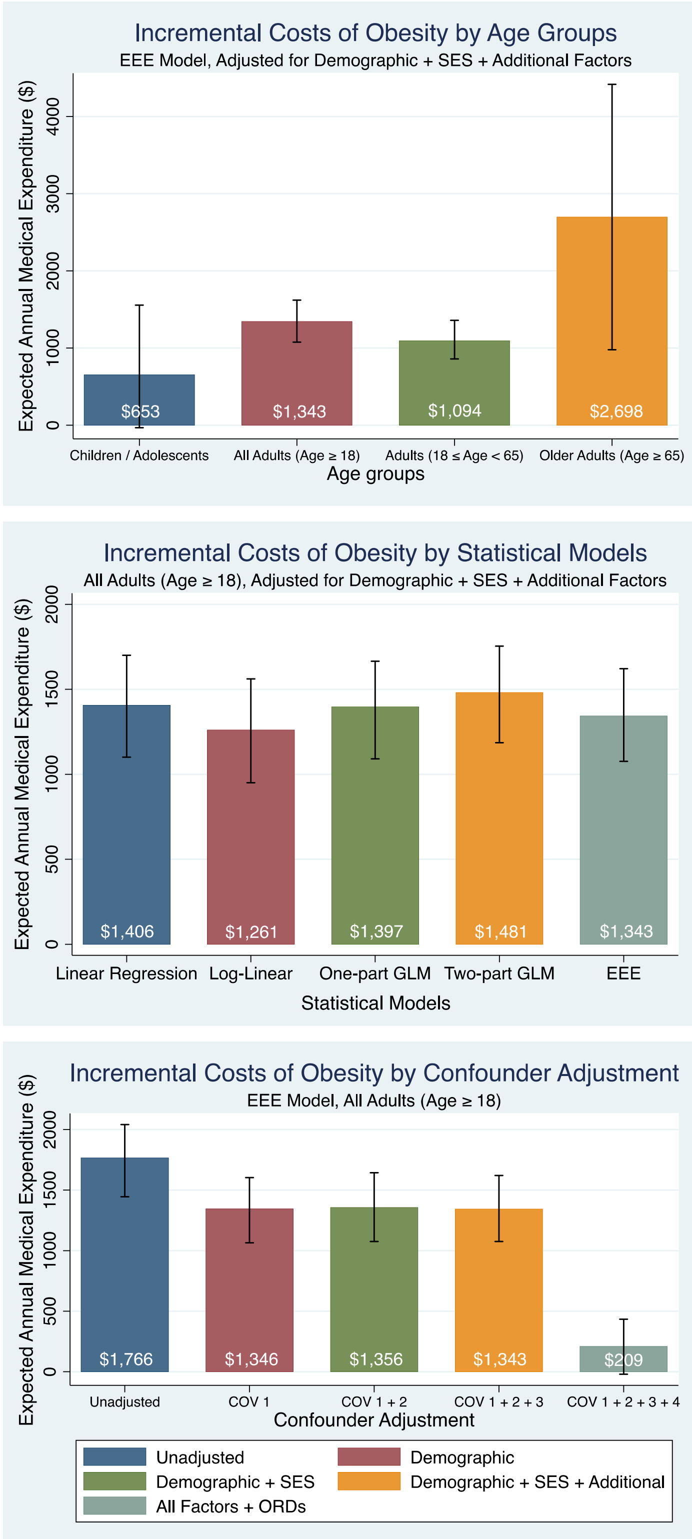
Confounding factor adjustment

For children, regardless of statistical models, the point estimates of the incremental costs of obesity were increased as we adjusted with more sets of possible confounding factors (up to cov1 + cov2 + cov3), despite a huge CI that made those estimates statistically insignificant. For adults, controlling for demographic, socioeconomic, and additional confounding factors (cov1 + cov2 + cov3) did not make any substantial impact on point estimates as well as statistical significance. However, by controlling for ORDs (cov4) that were available only for adults in this data set, the incremental costs of obesity reduced to one-fourth to one-seventh of the original estimates. Among all adults, the EEE model estimated the costs attributable to obesity as $1343 ($1076–$1621) controlling for all confounding factors except the comorbidity conditions, whereas after adding obesity-related comorbidities in the model the estimates were decreased to $209 (−$21 to $434), which was statistically insignificant, compared with the costs of the nonobese (Fig. 2; Table 4).

Discussion

This article provided a systematic review and meta-analysis of the 12 recently published articles that reported the medical care costs associated with obesity, and also performed an original analysis to understand the impact of study methodology on the magnitude of these estimates. From the meta-analysis, the pooled estimate of annual medical costs attributable to obesity was $1901 ($1239–$2582) in 2014 USD, accounting for $149.4 billion at the national level. The extremely high heterogeneity score from the meta-analysis signified the presence of heterogeneity between different studies due to the use of different data sets from multiple time periods, various statistical methods, and adjustment for a wide range of confounding factors to estimate the costs. Compared with the findings from the previously conducted systematic review that reported the incremental costs of obesity as $2046 (2014 USD) [13], the estimate from this analysis is very comparable.

From the empirical analysis, not surprisingly, different statistical methods did not have a significant impact on the



Note: EEE, extended estimating equation; SES, socio-economic status; GLM, generalized linear model; ORDs, obesity-related diseases

Fig. 2 – Impact of age groups, statistical models, and confounding factor adjustment on the estimates of costs attributable to obesity. EEE, extended estimating equation; GLM, generalized linear model; ORDs, obesity-related diseases; SES, socioeconomic status.

variability of the estimates in this analysis. However, we caution that this analysis does not endorse that any statistical model can be used in estimating highly skewed cost data. Ignoring the nature of cost data and misspecification of statistical models may lead to inefficient or sometimes biased estimates [32,33]. For all adults, controlling for the demographic and socioeconomic and additional factors (cov1 + cov2 + cov3), the EEE model, which had the best GoF among all models based on the GoF tests, reported $1343 ($1076–$1621) for the incremental costs of obesity. This result provides that the estimate of the national medical care costs attributable to obesity would be $94.3 billion ($75.6–$113.2 billion), which accounts for 3.8% (2.8%–4.3%) of national health expenditures in 2010 [35]. This estimate of medical costs attributable to obesity from the empirical analysis was lower than the pooled estimate from the meta-analysis. The reporting error in the BMI measure through self-reported height and weight is likely to bias the coefficient estimates, although the direction of bias is not clear. Also, the possibility of omitting unobserved confounders or reverse causality of obesity on medical costs is likely to underestimate the true costs attributable to obesity. The IV approach by Cawley et al. could address these problems using a weight of biological relative as an instrument. The estimate from the IV approach, however, may not be generalizable to the entire population because of the restriction of the study population to only adults aged 20 to 64 years with biological children aged 11 to 20 years.

The two most significant drivers of variability in the cost estimates were age groups and adjustment for obesity-related comorbid condition. First, as expected, there is no significant difference in costs attributable to obesity in children/adolescence population because of the presence of very few ORDs that may take a long time to develop among children. In contrast, the incremental costs of obesity were significantly higher than those for the nonobese for the adult population, and the older population reported significantly higher costs associated with obesity than did adults aged 18 to 65 years. However, because we included obesity-related comorbidity as a confounding factor in the model, the medical costs of obesity were not significantly higher that the costs among the nonobese. These findings confirmed that most, if not all, of the costs attributable to obesity are mainly caused by ORDs, and as age increases, the obese population is more likely to develop ORDs, incurring higher costs of obesity for the older population.

The main limitation of estimating costs attributable to obesity is the lack of distinction between costs of obesity caused by ORDs and costs of obesity care itself. If the ORDs are caused by the obesity, then by controlling for them, it estimates only the "partial" effect of obesity alone on the cost. However, by omitting such comorbidities as covariates, it estimates the "total effect" of obesity directly on cost and indirectly through mediators, the ORDs. Although the "partial" effect of obesity alone on medical costs was represented by the estimates controlling for ORDs (cov4) in my analysis, which were not significantly different from costs of the nonobese, the true "total effect" of obesity on costs is not easy to estimate, because the regression model could not capture the true counterfactual costs of obesity by just omitting comorbidities as covariates, ignoring the presence of ORDs in the nonobese population. Future study needs to be directed at estimating true counterfactual costs related to the absence/presence of obesity and ORDs.

After recognizing obesity as a disease, a national survey found that survey participants are more likely to support the disease classification of obesity, and they believe that this change would bring more attention to weight changes and more access to obesity treatment [36]. However, a recent evaluation of adherence to national obesity clinical practice guidelines found the lack of increase in documentation of diagnosis and planned management of obesity patients [37]. Thus, recognizing obesity as a disease may not lead to immediate changes in health care utilization or significant policy changes. However, what we can do is produce better evidence of effectiveness and cost-effectiveness of obesity treatment through future research. Then, better research alone will increase obesity treatment and reduce the burden of illness, and we hope the overall medical expenditure will be expected to decrease in the long run as we make more diligent efforts to fight against the obesity epidemic. (We appreciate valuable insights from an anonymous reviewer and David Arterburn.)

However, the utility of published estimates for the medical costs of obesity should be examined carefully, because of their wide variation, and the estimates should be applied cautiously in future research and health policy making.

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Supplementary Materials

Supplemental material accompanying this article can be found in the online version as a hyperlink at http://dx.doi.org/10.1016/j.jval.2016.02.008 or, if a hard copy of article, at www.valueinhealthjournal.com/issues (select volume, issue, and article).

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