

Public Health

Body mass index and healthcare costs: a systematic literature review of individual participant data studies

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Summary

Excess weight is associated with increased total healthcare costs, but it is less well known how the associations between excess weight and costs vary across different types of healthcare service. We reviewed studies using individual participant data to estimate associations between body mass index and healthcare costs, and summarized how annual healthcare costs for overweight (body mass index 25 to <30 kg/m²) and obese (≥30 kg/m²) individuals compared with those for healthy weight individuals (18.5 to <25 kg/m²). EMBASE and MEDLINE were searched from January 1990 to September 2016, and 75 studies were included in the review. Of these, 34 studies presented adequate information to contribute to a quantitative summary of results. Compared with individuals at healthy weight, the median increases in mean total annual healthcare costs were 12% for overweight and 36% for obese individuals. The percentage increases in costs were highest for medications (18% for overweight and 68% for obese), followed by inpatient care (12% and 34%) and ambulatory care (4% and 26%). Percentage increases in costs associated with obesity were higher for women than men. The substantial costs associated with excess weight in different healthcare settings emphasize the need for investment to tackle this major public health problem.

Keywords: Body mass index, healthcare costs, obesity, overweight.

Abbreviations: BMI, body mass index; IQR, interquartile range; US, United States.

Introduction

The prevalence of overweight and obesity has increased substantially in most countries in recent decades (1). Excess weight is linked to increased incidence of a number of chronic diseases, including type 2 diabetes, vascular disease, osteoarthritis, respiratory disease and certain cancers, and to premature mortality (2–4). There is also consistent evidence that increased body mass index (BMI) is associated with higher healthcare costs (5,6), and these costs are expected to grow as the prevalence of obesity increases (7).

Previous reviews examined the published literature on obesity and healthcare costs up to 2009; included population attributable fraction studies, modelling studies

and individual participant data or database studies; and focused on summarizing the total healthcare costs in relation to obesity and comparing these study types (5,6,8). These reviews reported average elevated total healthcare costs of around 30–40% for obesity compared with healthy weight based on only (6,8) or mostly (5) United States (US) studies.

In the present review, we focus exclusively, and in greater detail, on studies of associations between BMI and healthcare costs using individual participant data. Such studies enable direct and more detailed investigation of the associations, taking account of population heterogeneity (5), and offer greater capacity to overcome epidemiological challenges such as confounding, reverse causality and

measurement error (2). We also extend previous work by including relevant published literature up to 2016 and summarizing data on the relationship between BMI and annual healthcare costs for different healthcare services, for categories of participants by age and gender and by study characteristics and analytical methods.

Methods

Search strategy and selection criteria

MEDLINE and EMBASE were searched from 1 January 1990 to 19 September 2016. The search strategies, utilizing the search terms used in National Institute for Health and Care Excellence clinical guidelines in obesity (9) and in conjunction with an information specialist (see Acknowledgements section), are presented in Tables S1 and S2.

Following the exclusion of duplicate records, we reviewed titles, abstracts and full texts. Studies were retained at each stage if they met all of the following criteria: (1) peer-reviewed, full-text, English language research; (2) data on healthy weight people ($\text{BMI} < 25 \text{ kg/m}^2$) were included; (3) participants were not selected based on the presence of specific medical conditions, and the study did not exclude nonusers of healthcare services; (4) for interventional studies, outcome and exposure data were both observed prior to the receipt of the intervention; (5) the study sample was restricted to adults or results were estimated separately for adults; (6) the direct association between BMI (not stratified by other adiposity measures) and healthcare costs was estimated by using individual participant data; and (7) healthcare costs were estimated separately from other types of cost.

Reference lists of all included studies were scanned to identify any additional research not identified by the database search. Study screening and selection was carried out by SK. One thousand articles were randomly selected (following exclusion of duplicates) from the initial search, and the screening and selection process was independently carried out by a second reviewer on this sample (FF). FF identified more articles for both abstract and full-text review, but both reviewers independently selected the same set of studies as meeting all inclusion criteria after full-text review.

Where more than one study meeting all inclusion criteria used the same dataset (with at least some overlapping years) and methods, only the study with the highest quality rating (see succeeding texts) or, if of equal quality, the study providing the largest amount of information to data extraction, was retained. Studies using the same dataset but with non-overlapping years were all retained. Studies using the same dataset with some overlapping years were retained for data extraction if the analytical methods

differed materially; however, when summarizing quantitative results, only one paper was retained, following the criteria defined in the preceding texts.

Quality assessment

Study quality was assessed by using the National Heart, Lung and Blood Institute's quality assessment tool for observational cohort and cross-sectional studies (see Table S3) (10). This tool is focused on assessing the internal validity of a study and includes questions to help identify risk of selection bias, information bias, measurement bias and confounding. Studies were classified as being of good, fair or poor quality according to the reviewers' assessment of the overall risk of bias arising from these different sources. Both reviewers (SK and FF) applied the quality assessment tool to all studies which met the inclusion criteria, and disagreements on overall quality assessments (regarding 11 studies) were resolved through discussion.

Data extraction

For each study which met the inclusion criteria, detailed information was extracted on participant characteristics, the reporting of BMI, the assessment of costs, the analytical methods and the results. Results for each study were summarized in terms of relative increases in mean costs in comparison with healthy weight reference group where available, and otherwise in comparison with the study-specific reference group. Where relevant, overall results are presented for total healthcare costs, and separately for inpatient, ambulatory (defined to include both specialist outpatient care and primary care) and medication costs (which can include over-the-counter medications); the specific components constituting each of these categories vary between studies. Total healthcare costs were considered observed if a study included, at a minimum, inpatient, ambulatory and prescription medication costs (some studies included additional services like nursing care) or if the study defined costs as total without specifying the specific components. For total healthcare costs, results are also presented for subgroups by age and gender. SK extracted data from each study; FF independently extracted data from 14 studies. No disagreements were identified.

Data analysis – Quantitative summaries of results

To maximize the comparability of the results between studies and to generate appropriate summary estimates, results from each study were converted where possible to percentage differences in mean costs for underweight ($\text{BMI} < 18.5 \text{ kg/m}^2$), overweight ($\text{BMI} 25 \text{ to } < 30 \text{ kg/m}^2$) and obesity categories (class I: $30 \text{ to } < 35 \text{ kg/m}^2$; class II: $35 \text{ to } < 40 \text{ kg/m}^2$; and class III: $\geq 40 \text{ kg/m}^2$), as well as a

combined obesity category ($\text{BMI} \geq 30 \text{ kg/m}^2$), compared with a healthy weight category, following the categorization recommended by the World Health Organization (11). The BMI range of the healthy weight reference group differed between studies; however, all were within 18.5 to $<25 \text{ kg/m}^2$, except one study which included a small number of underweight individuals. Notably, studies in Asian populations tended to use lower BMI cut-points, which were argued to be more relevant to the target population (12). Where these were explicitly interpreted in terms of the overweight and obesity categories defined in the preceding texts, results were mapped to these categories. Studies which did not report results which could be converted to percentage increases in mean costs by BMI categories were excluded from quantitative summaries.

The results were summarized across studies by the median (and interquartile range [IQR]) of percentage increases in mean costs (we henceforth refer to these as median estimated effects). These summary statistics are presented graphically by using box plots. Studies were included in the summary estimates if annual mean costs (or a shorter period of time but not relating to a single event) were presented or could be derived for the defined BMI categories of interest relative to an appropriate healthy weight group. Sensitivity analyses were performed: including only studies of good and fair quality; including partial duplicate studies, i.e. those studies with some but not complete overlap in time periods; excluding studies in Asian populations in which non-standard BMI categorizations were used; and excluding studies with outcome periods less than 1 year.

Summary results are reported for total healthcare, inpatient care, ambulatory care and medication costs. For total healthcare costs, the results were also presented by gender (male and female), by study population as a proxy for age (all adults, only working age adults, only middle-aged and/or elderly; following the precedent of previous reviews (6,8)) and according to whether the study was conducted in the US (the source of the majority of included studies) or elsewhere. Summary results for total healthcare costs were also reported by overall study quality (good/fair and poor) and for selected data characteristics and analytical methods: mean length of study follow-up (>1 year and ≤ 1 year), overall study sample size ($\geq 10,000$ and $<10,000$), whether the study was prospective (i.e. information for the calculation of BMI was taken at or prior to the start of the outcome data collection period), whether the study adjusted appropriately for confounders (defined as adjusting for basic demographic characteristics like age and gender, measures of deprivation or socioeconomic status and/or other health behaviours like smoking, while not adjusting for characteristics on the causal pathway between BMI and costs like diabetes or coronary heart disease) and whether an explicit attempt was made to

account for confounding by pre-existing disease (e.g. exclusion of individuals with pre-existing cancers or other conditions potentially affecting weight and costs, exclusion of early years of follow-up or the use of explicit statistical techniques like instrumental variable regression).

Results

Search strategy

The literature search yielded 13,385 records (9,978 from EMBASE and 3,407 from MEDLINE) (Fig. 1). One hundred twenty-nine studies were included in the full-text review after exclusion by titles and abstracts; 73 met all inclusion criteria. Two further studies were identified and included following review of the reference lists of included articles. In total, 75 studies were included in the systematic review (13–87).

Data and methods of studies included in review

Table 1 summarizes the characteristics of included studies (complete information for each study is presented in Table S4). The median sample size across all studies was 11,572 (IQR: 4,545 to 29,925). Most studies ($n = 44$, 59%) were based on individuals' resident in the US. Almost half of studies ($n = 33$, 44%) sampled general, but not necessarily representative, adult populations; other study samples were restricted to adults of working age (usually 18 to 65 years; $n = 24$, 32%) or to middle-aged or older adults only (aged 40 years and above; $n = 18$, 24%). Majority of studies derived BMI from self-reports of either or both height and weight ($n = 55$, 73%), obtained data on resource use or costs from mainly routine administrative data sources ($n = 44$, 59%) and collected sufficient data to allow the calculation of total healthcare costs ($n = 54$, 72%). Approximately half of studies ($n = 39$, 52%) collected information on outcomes for 1 year or less, and in 31 studies (41%), BMI was recorded prior to the outcome assessment period (median follow-up time in these studies was 1.5 years).

Most studies used a statistical model to relate BMI to healthcare costs ($n = 65$, 87%) and made some adjustments for potential confounders without over-adjusting for obesity-related conditions ($n = 44$, 59%) (Table S5). Relatively few studies (18, 24%) attempted to deal with confounding by pre-existing disease by excluding individuals with known conditions that could influence both weight and costs or by excluding the first few years of follow-up to account for unobserved conditions; four studies used instrumental variable regression either as a main or supplementary analysis.

Body mass index was almost always categorized ($n = 70$, 93%): 49 studies used standard WHO BMI classifications,

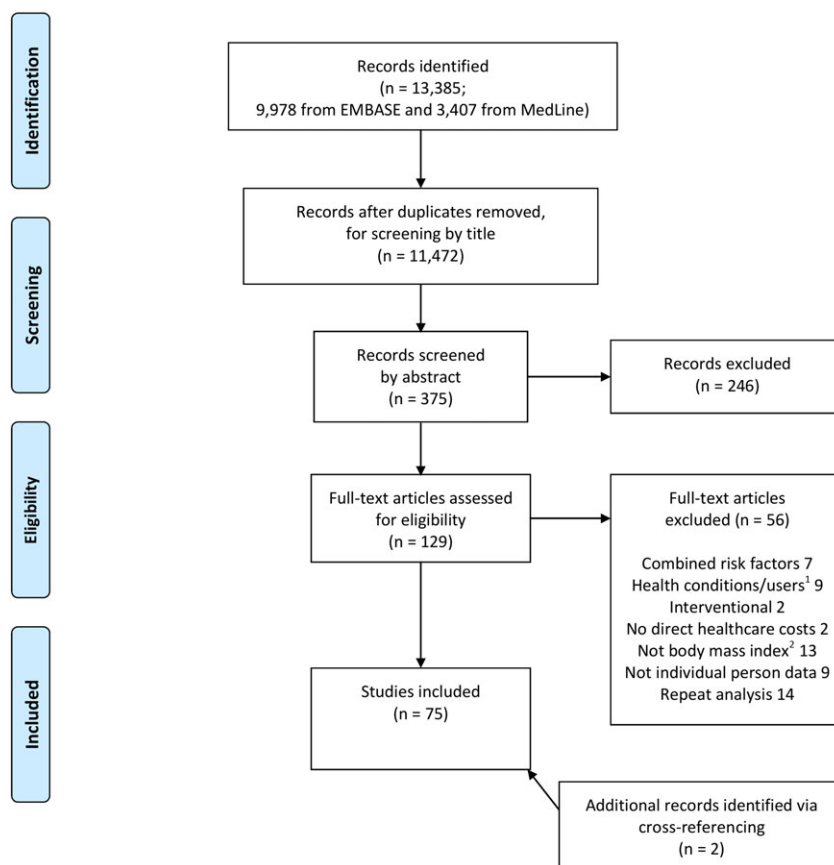


Figure 1 Search results and exclusions.¹ Studies were excluded when individuals were selected based on the presence of certain pre-existing conditions (or because they were at particularly high risk) or because they were all users of healthcare services.² Studies were excluded if used measures of adiposity other than body mass index, if stratified body mass index by other measures of adiposity (usually waist circumference) and did not present unstratified results, if estimated costs following changes in body mass index or if did not state the measure of adiposity used. [Colour figure can be viewed at wileyonlinelibrary.com]

and 4 studies all from countries in east Asia used other classifications considered more applicable to their source population. Sixty-four studies (85%) presented estimates of annual costs in relation to BMI. Among all studies, 30 did not present results by any subgroup of participants, 18 presented results by age categories, 28 by gender and 4 by race and/or ethnicity. Overall, 23 studies (31%) were classified as good quality, 28 (37%) as fair and 24 (32%) as poor (Table S6).

Summary of results of included studies

Of the 75 studies included in the review, we excluded studies from the summary of quantitative results if estimates of percentage costs for BMI categories could not be derived ($N = 16$); an appropriate healthy weight group was not used ($N = 11$); cumulative costs over more than 1 year were presented, and not corresponding annual costs ($N = 5$); overweight and obesity categories were combined ($N = 2$); results were estimated as geometric rather than arithmetic means ($N = 1$); or results were only presented by categories

of cost other than those defined ($N = 1$). A further five studies were considered partial duplicates and excluded. In total, 39 studies contributed results to the main summary of estimates or to sensitivity analyses. Lists of included and excluded studies and reasons for exclusion are presented in Table S7. Characteristics of included and excluded studies are presented in Table S8.

There was substantial variation between studies in estimates of average increases in annual costs associated with overweight and obesity for all types of healthcare service (Fig. 2 and Table 2; see Table S9 for detailed results from each study). Across studies, median percentage increases in annual total healthcare costs for overweight and obesity were 12% (IQR: 5 to 24) and 36% (25 to 54) respectively. Median estimated increases for overweight and obesity were strongest for medication costs (18% [15 to 27] and 68% [51 to 77] respectively), followed by inpatient costs (12% [2 to 27] and 34% [22 to 44]). Ambulatory care costs were substantially elevated for obese (26% [19 to 31]) but not overweight (4% [−2 to 28]) individuals. The same ordering of results was evident in

Table 1 Characteristics of studies included in the systematic review, by study quality

	All studies	Study quality		
		Good	Fair	Poor
Number of studies (number contributing to quantitative summary ^a)	75 [39]	23 [14]	28 [15]	24 [10]
Region				
United States	44 (59)	14 (61)	18 (64)	12 (50)
Europe	15 (20)	3 (13)	4 (14)	8 (33)
Asia	7 (9)	3 (13)	3 (11)	1 (4)
Other ^b	9 (12)	3 (13)	3 (11)	3 (12)
Study population				
All adults	33 (44)	9 (39)	12 (43)	12 (50)
Working age adults	24 (32)	8 (35)	8 (29)	8 (33)
Middle-aged or elderly	18 (24)	6 (26)	8 (29)	4 (17)
Sample size				
Median [interquartile range]	11,572 [4,545, 29,925]	12,520 [7,544, 21,669]	17,118 [6,743, 31,205]	5,990 [2,204, 30,132]
≥10,000 participants	39 (53)	14 (61)	16 (59)	9 (38)
<10,000 participants	35 (47)	9 (39)	11 (41)	15 (62)
Body mass index reporting				
Measured	20 (27)	6 (26)	7 (25)	7 (29)
Self-reported	50 (67)	17 (74)	21 (75)	12 (50)
Mixed ^c	5 (7)	0 (0)	0 (0)	5 (21)
Prospective study				
Yes	31 (41)	20 (87)	9 (32)	2 (8)
No	44 (59)	3 (13)	19 (68)	22 (92)
Outcome data				
Administrative records	44 (59)	11 (48)	18 (64)	15 (62)
Self-reported	16 (21)	4 (17)	5 (18)	7 (29)
Mixed	15 (20)	8 (35)	5 (18)	2 (8)
Length of outcome data collection period				
>1 year	36 (48)	15 (65)	14 (50)	7 (29)
≤1 year	39 (52)	8 (35)	14 (50)	17 (71)
All types of direct healthcare cost included				
Yes	54 (72)	17 (74)	21 (75)	16 (67)
No	21 (28)	6 (26)	7 (25)	8 (33)

Values are number of studies (percentage) unless otherwise stated.

^aStudies contributing to results presented in Table 2 and Fig. 1. It includes partial duplicates.

^bCanada, Australia and South Africa.

^cThree studies used mostly measured weight but mostly self-reported height; two studies measured height and weight for some but not all participants.

most studies which presented results by more than one subcategory of healthcare costs: obesity was associated with greater percentage increases in inpatient than in ambulatory costs in 8 of 12 studies which made this comparison and greater percentage increases in medication costs compared with either inpatient costs (five of seven studies) or ambulatory costs (seven of seven studies).

There was also evidence of increasing costs with increasing grades of obesity (Fig. S1). Median estimated percentage increases in total healthcare costs for obesity grades I (BMI 30 to ≤35 kg/m²), II (35 to ≤40 kg/m²) and III (≥40 kg/m²) compared with healthy weight were 22% (IQR 20 to 25), 45% (25 to 49) and 50% (48 to 77)

respectively. Underweight was associated with elevated costs for total health care (13% [5 to 16] higher) and inpatient care costs (53% [25 to 56] higher), but not with ambulatory care (0% [−10 to 2] higher) or medication costs (7% [−3 to 9] higher). Median estimated percentage changes in costs were similar when including only studies of good or fair quality, including the partial duplicate studies, excluding studies using BMI cut-points for Asia or excluding studies with an outcome period less than 1 year (Table S10).

For total healthcare costs, the median estimated percentage increase in costs associated with obesity across studies appeared to be slightly greater in women than in men: 50% (39 to 65) versus 40% (23 to 50). Average increases of 24% associated with overweight were observed for both men and women (Tables 2 and S11). In studies that presented results for both men and women, percentage increases in costs were higher for women than for men in six of eight studies for overweight and in seven of nine studies for obesity. The median estimated percentage increases in costs associated with obesity were lower for older populations compared with populations of only working age adults (30% [29 to 34] versus 45% [33 to 63]) but similar for overweight (Table 2). Comparisons across studies presenting results for different age groups are limited by the inconsistent age categories used and the small number of studies. However, there was some indication of increasing percentage costs for overweight and obesity from young adulthood up to late middle age (up to around 60 to 65 years), whereas for older adults, percentage cost increases decreased with age (Table S12). The average percentage increases in costs associated with overweight and obesity across studies conducted in US populations were similar to those conducted in other populations (Table 2).

For total healthcare costs, the median estimated percentage cost increases associated with obesity were marginally higher for good/fair studies compared with poor studies (36% [IQR 28 to 53] versus 28% [20 to 50]) (Table 3). For overweight, the median estimated percentage increases in costs were similar for good/fair and poor studies (12% [4 to 24] versus 12% [7 to 18]). The median estimated percentage increases in costs associated with overweight and obesity were similar across studies categorized by length of study follow-up, overall study sample size and whether the study made an explicit attempt to deal with potential confounding by pre-existing disease. The median estimated percentage increases in costs for overweight and obesity were higher among prospective studies than cross-sectional or retrospective studies (21% [11 to 26] versus 9% [5 to 16] for overweight and 39% [33 to 59] versus 28% [21 to 42] for obesity). Studies which adjusted appropriately for confounders reported a smaller average percentage increase in costs for obesity

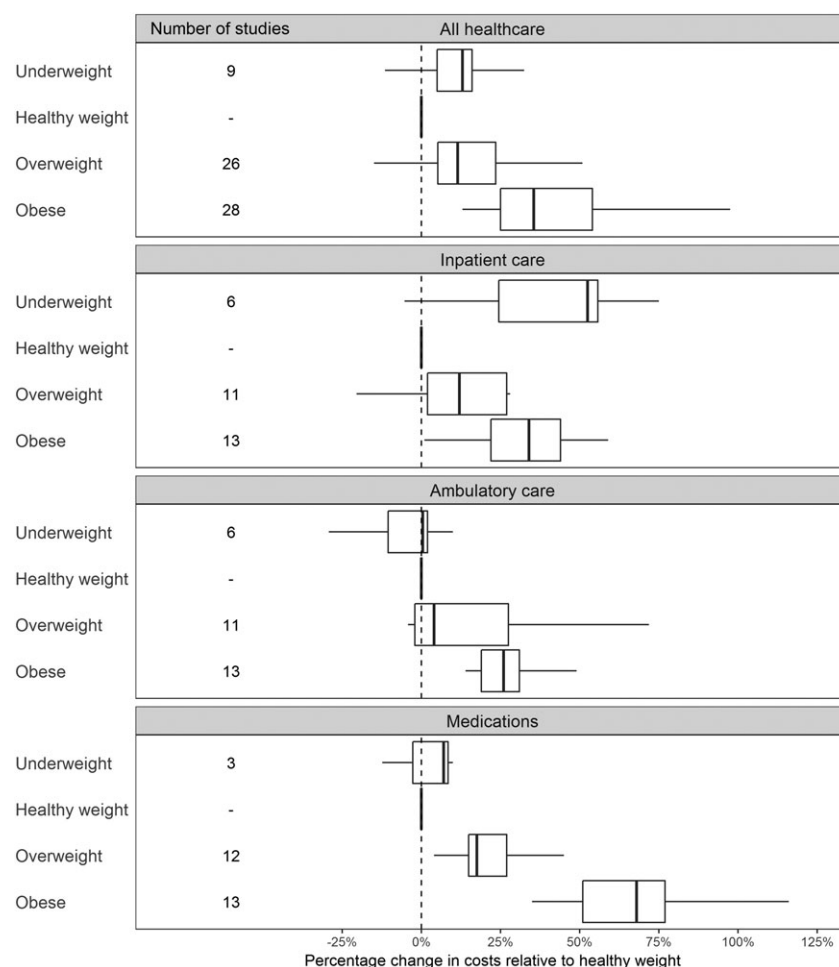


Figure 2 Percentage changes in healthcare costs compared with healthy weight, overall and for different healthcare services. The central bold bar reports the median percentage change in costs. The horizontal extent of the box represents the interquartile range (i.e. 25th and 75th percentiles). The left-hand bar is the larger of 1.5 times the interquartile range below the median or the lowest observed result. The right-hand bar is the smaller of 1.5 times the interquartile range above the median or the highest observed result.

(33% [26 to 48] versus 46% [25 to 77]) and for overweight (10% [4 to 19] versus 22% [11 to 55]), compared with those that did not adjust appropriately for confounders. Findings in studies not included in the main quantitative analyses were consistent with the reported summary results, with higher levels of BMI typically associated with greater healthcare costs.

Discussion

This systematic review summarized the results from studies using individual participant data to estimate healthcare costs in relation to BMI. Despite the large variations in data and methods used, some clear patterns emerged. Overweight and obesity were consistently associated with increased healthcare costs overall and for most major types of healthcare service. Based on estimates of the prevalence of overweight and obesity in the UK and

the US (88,89), the estimated 12% and 36% increases in total annual healthcare costs for overweight and obesity respectively imply that overweight and obesity combined are associated with around 12% of adult healthcare expenditure in the UK and 15% in the US. There was also evidence of progressive increases in annual costs with increasing severity of obesity. The percentage increases in annual costs for overweight and obesity were greatest for medications, followed by inpatient care, and then ambulatory care.

Proportional increases in healthcare costs associated with obesity were higher among women than among men. This is consistent with a previous review based on US studies only, which found absolute costs of overweight and obesity to be higher for women than for men (6). The BMI-cost association depends on a number of factors including the prevalence of different conditions related to excess weight, the extent to which excess weight influences the risks for

Table 2 Percentage changes in annual healthcare costs compared with healthy weight, by healthcare service type and population categories

	Underweight		Overweight		Obese	
	Number of studies	Median cost increase (IQR)	Number of studies	Median cost increase (IQR)	Number of studies	Median cost increase (IQR)
Type of healthcare service						
All health care	9	13% (5, 16)	26	12% (5, 24)	28	36% (25, 54)
Inpatient	6	53% (25, 56)	11	12% (2, 27)	13	34% (22, 44)
Ambulatory	6	0% (−10, 2)	11	4% (−2, 28)	13	26% (19, 31)
Medications	3	7% (−3, 9)	12	18% (15, 27)	13	68% (51, 77)
Total healthcare costs, by population category						
Gender						
Male	4	7% (−3, 39)	8	24% (17, 26)	9	40% (23, 50)
Female	4	−17% (−23, −10)	9	24% (9, 40)	10	50% (39, 65)
Age						
All adults	5	5% (−10, 13)	13	9% (6, 19)	14	34% (25, 48)
Working age adults	1	13%	8	16% (7, 27)	8	45% (33, 63)
Middle-aged and elderly	3	34% (25, 42)	5	13% (4, 15)	6	30% (29, 34)
Study conducted in the United States						
Yes	2	32% (22, 42)	14	12% (7, 21)	15	36% (30, 52)
No	7	13% (−2, 15)	12	12% (4, 24)	13	30% (25, 54)

IQR, interquartile range.

Table 3 Percentage changes in total annual healthcare costs compared with healthy weight, by study characteristics

	Underweight		Overweight		Obese	
	Number of studies	Median cost increase (IQR)	Number of studies	Median cost increase (IQR)	Number of studies	Median cost increase (IQR)
Overall results	9	13% (5, 16)	26	12% (5, 24)	28	36% (25, 54)
Quality assessment rating						
Good/fair	8	14% (1, 20)	20	12% (4, 24)	22	36% (28, 53)
Poor	1	13%	6	12% (7, 18)	6	28% (20, 50)
Prospective study design						
Yes	4	3% (−13, 20)	10	21% (11, 26)	11	39% (33, 59)
No	5	13% (13, 15)	16	9% (5, 16)	17	28% (21, 42)
Length of study follow-up						
>1 year	5	13% (−10, 16)	14	12% (8, 24)	15	35% (29, 52)
≤1 year	4	14% (11, 24)	12	12% (5, 20)	13	36% (25, 54)
Study sample size						
≥10,000 participants	7	13% (−2, 14)	16	9% (5, 22)	17	31% (25, 50)
<10,000 participants	2	34% (25, 42)	10	15% (11, 23)	11	36% (29, 56)
Appropriate adjustment for confounders						
Yes	7	13% (9, 25)	20	10% (4, 19)	22	33% (26, 48)
No	2	3% (−4, 9)	6	22% (11, 55)	6	46% (25, 77)
Attempt to account for confounding by pre-existing disease						
Yes	4	2% (−13, 14)	7	10% (9, 19)	8	33% (27, 37)
No	5	15% (13, 34)	19	15% (5, 23)	20	37% (25, 55)

IQR, interquartile range.

these conditions and the costs of these conditions, all of which may differ by gender, among other factors. A meta-analysis of the associations between obesity and a large range of conditions found obesity to have stronger associations with the incidence of diabetes, coronary artery disease and hypertension among women compared with men, and obesity is also linked to some female-specific cancers (4).

It was not possible to categorize studies by mutually exclusive age categories. Instead, we followed the precedent of previous reviews in defining proxy age categories based on the distribution of age in the study population (6,8). We did not observe clear patterns in the BMI–cost relationship according to these proxy age categories. Primary studies which estimated the BMI–cost relationships in separate and mutually exclusive age

categories have consistently found obesity to have a stronger impact among middle-aged individuals compared with younger adults (<40 years) (44,45,62,67,73). This relationship, also observed in previous reviews (6), may be a result of longer exposure to excess weight and the fact that many consequences of obesity, including diabetes, coronary heart disease and osteoarthritis, take many years to manifest (90). Primary studies which directly compared the very elderly to those in middle age tended to find weaker associations among the elderly (44,48,62,67,73), consistent with much of the epidemiological evidence for associations between excess weight and risk of major diseases and mortality (2,3,91–93). Healthcare costs are strongly increasing with age (94–96), and so even if percentage increases in costs are smaller among elderly individuals, absolute increases in costs may be greater than for younger individuals (97).

Being underweight was also associated with increased total healthcare costs across the reviewed studies, and this was driven predominantly by strong associations between underweight and inpatient care costs and among older populations. However, these associations are likely to be at least in part a result of bias due to pre-existing disease (reverse causation) and residual confounding by smoking and other characteristics. Epidemiological studies have shown that excluding early years of follow-up, restricting analysis to non-smokers or to the physically active and excluding individuals with known cancer and other pre-existing conditions reduce the estimated risks associated with underweight (2,3,98). Similar effects have also been demonstrated in cost studies after excluding 5 years of outcome data or restricting analysis to those without serious illnesses (48,62). To a much lesser degree, these factors may also affect estimates for overweight and obese categories. In addition, few studies presented results for underweight, and in those that did, the number of participants who were underweight was small.

We found the pattern of results to be consistent across a large range of study design and methodological features. We found no evidence that relative costs of overweight and obesity differed systematically according to the sample size or follow-up time of studies. A previous review, based on a much smaller number of studies from only the US, found studies based on smaller sample sizes and, with lower follow-up times, reported higher relative cost increases for obesity (8). The results were also similar regardless of overall study quality. However, median percentage total healthcare cost increases were larger in prospective studies (i.e. studies which collected height and weight information prior to the outcome data collection period) than in cross-sectional or retrospective studies, and smaller in studies that appropriately controlled for confounding factors compared with those that did not; in

studies with both of these features, the results were very similar to the overall results.

This review is subject to a number of limitations. It was restricted to English language, peer-reviewed research and relevant studies in other languages or in the non-peer reviewed literature may therefore have been excluded. Because of the often limited reporting of measures of uncertainty, as well as considerable heterogeneity between studies in terms of data (including in the components of costs included), healthcare settings, methods used (including in the categorization of BMI) and presentation of results, a meta-analysis was not performed. Consequently, it is not possible to make formal inferences about differences in relative cost estimates. Comparisons of relative effects across weight categories, types of healthcare service, participant characteristics and study characteristics may be confounded by differences between studies. However, studies which reported results for multiple categories of interest – e.g. different healthcare services or participant groups – showed similar patterns to those observed across studies.

This review has demonstrated that excess weight is associated consistently with higher healthcare costs overall and across a range of important healthcare services, for different population strata, and in different healthcare settings. These results highlight the need for investments in cost-effective programmes designed to reduce and prevent obesity. To inform healthcare planning, detailed information is needed on costs for different grades of obesity and on the contributions of different health conditions to the overweight and obesity-attributable costs in different healthcare settings.

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Conflict of interest statement

No conflict of interest was declared.

Supporting information

Additional Supporting Information may be found online in the supporting information tab for this article. <https://doi.org/10.1111/obr.12560>

Table S1. EMBASE search terms.

Table S2. MEDLINE search terms.

Table S3. National Heart, Lung and Blood Institute's quality assessment tool for cohort and cross-sectional studies.

Table S4. Summary of data characteristics of all studies.

Table S5. Characteristics of the methods of included studies.

Table S6. Quality assessment results.

Table S7. List of studies contributing and not contributing (with reasons) to the quantitative summaries.

Table S8. Characteristics of studies contributing and not contributing results to the quantitative summary.

Table S9. Relative costs for each study, by type of healthcare service.

Table S10. Median (interquartile range) percentage change in costs for sensitivity analyses.

Table S11. Relative costs in included studies, by gender.

Table S12. Relative costs in included studies, by age category.

Figure S1. Relative costs compared with normal weight by BMI category and healthcare service type.

References

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