doi: 10.1111/obr.12649

Pediatric Obesity/Public Health

The lifetime costs of overweight and obesity in childhood and adolescence: a systematic review

D. Hamilton[1], A. Dee[1] and I. J. Perry[2]

[1]Department of Public Health, Health Service Executive Mid-West, Mount Kenneth House, Limerick, Ireland, and [2]Department of Epidemiology and Public Health, University College Cork, Cork, Ireland

Received 25 July 2017; revised 24 October 2017; accepted 24 October 2017

Address for Correspondence: D. Hamilton, Department of Public Health, Health Service Executive Mid-West, Mount Kenneth House, Henry Street, Limerick, Ireland.
E-mail: douglas.hamilton@hse.ie

Summary

Background: Research into lifetime costs of obesity in childhood is growing. This review synthesizes that knowledge.
Methodology: A computerized search of the international literature since 2000 was conducted. Mean total lifetime healthcare and productivity costs were estimated and inflated to 2014 Irish euros.
Results: This resulted in 13 published articles. The methodology used in these studies varied widely, and only one study estimated both healthcare and productivity costs. Cognizant of this heterogeneity, the mean total lifetime cost of a child or adolescent with obesity was €149,206 (range, €129,410 to €178,933) for a boy and €148,196 (range, €136,576 to €173,842) for a girl. This was divided into an average of €16,229 (range, €6,580 to €35,810) in healthcare costs and €132,977 (range, €122,830 to €143,123) in productivity losses for boys and €19,636 (range, €8,016 to €45,283) and €128,560, respectively, for girls. Income penalty accounted for the greater part of productivity costs, amounting to €97,118 (range, €86,971 to €107,264) per male adolescent with obesity and €126,108 per female adolescent.
Conclusions: Healthcare costs and income penalty appear greater in girls while costs because of workdays lost seem greater in boys. There is proportionality between body mass index and costs. Productivity costs are greater than healthcare costs.
Keywords: Childhood, costs, lifetime, obesity.

Abbreviations: OECD, Organization for Economic Co-operation and Development; WHO, World Health Organization; BMI, body mass index; CPI, Consumer Price Index; CSO, Central Statistics Office; PPP, purchasing power parity.

Introduction

The Organization for Economic Co-operation and Development (OECD) ranks obesity as the largest threat to public health in the Western world today, along with smoking (1). Numbers affected are still rising sharply, particularly in children (2), causing morbidity such as type 2 diabetes already during childhood years (3). In Europe, while childhood obesity rates are lower than in the United States (US), there has been a substantial increase over the last decade. In 2013, the prevalence of overweight and obesity among children and adolescents aged 2 to 19 years, using International Obesity Taskforce cut-off points (4), 24.2% in boys and 22.0% in girls in Western Europe, 21.3% in boys and 20.3% in girls in Central Europe and about 19% in both sexes in Eastern Europe (5).

Of particular concern is that it has been shown that children with obesity grow up to be adults with obesity, continuously adding fuel to this already significant public health threat (6). The World Health Organization (WHO) currently ranks excess body weight as third on the list of health risks in high income countries, responsible for

8.4% of deaths and 6.5% of disability adjusted life years (7).

The increasing prevalence of overweight/obesity in children comes with increases in both current childhood and future adult morbidity and mortality and concomitant costs. It is thought that most of the costs are incurred in adult life, and a reduction in adult obesity prevalence has the potential to realize substantial health and economic benefits. One of the primary strategies to address adult obesity is through early prevention targeting children and adolescents. A recent review by Hollingworth et al. of lifestyle interventions to treat overweight or obesity of children in the United Kingdom estimated that these early life interventions could be cost-saving, although this saving did not emerge until the sixth decade of life with a discounted cost per life year gained of £13,589 (8). However, childhood obesity also carries its own excess costs during childhood. Finally, the excess morbidity (and costs) caused by obesity in adulthood is greater the longer the person has been obese, especially if present from adolescence or childhood.

Definitions of overweight and obesity

The WHO definition of obesity is widely used for adults and often also for adolescents. This defines overweight in adults as a body mass index (BMI) equal to or greater than 25 kg m^{-2} and obesity as a BMI equal to or greater than 30 kg m^{-2}, further subdivided into class I obesity when the BMI is 30.0–34.9 kg m^{-2}, class II with BMI 35.0–39.9 kg m^{-2} and class III obesity with a BMI of 40 kg m^{-2} and above (9). However, when it comes to childhood and adolescent overweight and obesity, the WHO definitions, based on a number of standard deviations above the respective WHO Growth Reference medians, are not as universally applied (10), and many definitions prevail.

Types of costs

The economics literature commonly refers to direct and indirect healthcare costs and direct and indirect non-healthcare costs (including productivity losses). However, in the published literature on childhood obesity, costs tend to be divided into two types: direct (health care) costs and indirect (productivity loss) costs. Key healthcare costs include drug costs, hospital in-patient costs, hospital outpatient costs and primary care (general practitioner) costs. Nursing home costs are also in this category but rarely included because of the difficulty in getting accurate disease-specific data. Productivity losses are typically costs to society because of disease related reduction in productivity. They can be divided into costs because of workdays lost and income penalty. Costs because of workdays lost most commonly uses the human capital approach (lost workdays accumulated because of absence, early retirement and mortality because of disease), but the friction cost approach is also used (where it is assumed that the absent worker is replaced after, e.g. 6 months). Presenteeism, i.e. reduced productivity because of illness while at work, may cause a greater loss of obesity-related productivity than absenteeism. Presenteeism has been estimated to cost employers \$3,792 $year^{-1}$ in a recent American study, equivalent to 1 month of lost productivity per annum (11). The age marking the end of productivity is usually set at the civil service retirement age, but some consider people as being economically productive for a number of years after that, albeit usually at a reduced rate (12). Finally, income penalty refers to the lower salary level that adolescents may be destined for as a result of their overweight or obesity (13).

Types of studies

A number of different approaches are used to calculate the direct medical costs associated with health risks such as obesity. Studies estimating lifetime costs either follow large cohorts recording real changes or use simulation models that fall into three main categories: micro-simulations, which simulate entire populations and examine forecasted results by different characteristics included in the model, such as diseases, risk factors and age-groups; cohort-based models, which may combine data from a range of cross-sectional and/or longitudinal sources; and macro-models, which aim to forecast total health expenditure, commonly using time-series and cross-sections of aggregate indicators. Micro-simulations focus on individuals as the unit of analysis for the cost projection, cohort-based models stratify individuals into groups and macro-level models focus on total health expenditure as the unit of analysis. Macro-models use econometric regression analysis to fit data. They are the least demanding in terms of data requirements but are most appropriate for short-term projections in the presence of clear and undisturbed trends. Cohort-based models focus on demographic drivers of health expenditure growth and tend to be less data intensive and less complex than micro-simulation models. Each cell in the cohort model is associated with an average cost. More advanced cohort models take into account trends in morbidity rates and factors influencing those trends such as obesity (14).

Rationale for review

Cognizant of the significant prevalence of childhood overweight and obesity, it is important to determine its excess costs to society. A recent review of the US literature (15) identified six papers, all looking at lifetime direct costs of childhood obesity only. That review concluded that more work needs to be done in this area, especially on indirect costs. This is of particular relevance as indirect costs seem to be greater than direct costs (12). In spite of this, there have been no recent systematic reviews on lifetime costs of childhood obesity that include developed countries outside the USA, and none whatsoever that look at indirect lifetime costs or total lifetime costs of childhood obesity. This systematic review therefore aims to fill this knowledge gap by gathering the evidence available in the global literature since 2000 in English on the average total lifetime costs, both healthcare and productivity loss costs, per child or adolescent with obesity or overweight. It looks at costs from a societal perspective. Estimating the total cost per child with obesity or overweight in defined units, such as Irish 2014 euros, adds usefulness as it enables easy estimation of the total lifetime costs of the childhood age-group of any population by applying current obesity or overweight prevalence rates, simple tables of purchase power parities (PPPs) and indices of inflation to population census data.

Methods

Data sources and search strategy

The search methodology laid out by Preferred Reporting Items for Systematic Reviews and Meta-analyses was used as guidance. Two independent researchers undertook an extensive computerized search of eight databases, chosen after consultation with the broader Safefood project team (Acknowledgements). The Cochrane, Pubmed, Web of Science, Excerpta Medica database and Elton B. Stephens Company Information Services databases were explored. The Elton B. Stephens Company Information Services search used a combined search of Medical Literature Analysis and Retrieval System Online, Academic Search Complete, Cumulative Index to Nursing and Allied Health Literature and The American Economic Association's database for economic literature.

A combination of the search words 'obesity', 'obese', 'overweight', 'Body Mass Index', 'BMI', 'adiposity', 'child', 'school children', 'schoolchildren', 'pediatric', 'paediatric', 'boys', 'girls', 'cost', 'economic', 'direct', 'medical cost', 'healthcare cost', 'indirect', 'productivity' and 'absenteeism' were used, applying mesh and truncation (*) functions as appropriate for each database. As an example, Pubmed was searched as follows: 1 Obesity [mesh]; 2 Overweight [mesh]; 3 Obese; 4 Body Mass Index [mesh]; 5 BMI; 6 Adipos*; 7 Child [mesh]; 8 Child*; 9 School children; 10 Schoolchildren; 11 Pediatr*; 12 Paediatr*; 13 Boys; 14 Girls; 15 Cost [mesh]; 16 Economic; 17 Direct [mesh]; 18 Medical cost; 19 Healthcare; 20 Indirect [mesh]; 21 Productivity; and 22 Absen*. Combinations used were then as follows: 1 OR 2 OR 3 OR 4 OR 5 OR 6 = 23; 7 OR 8 OR 9 OR 10 OR 11 OR 12 OR 13 OR 14 = 24; 15 OR 16 = 25; 17 OR 18 OR 19 OR 20 OR 21 OR 22 = 26; 23 AND 24 AND 25 AND 26. The combinations used for searching the other databases can be acquired on request from the corresponding author.

Limits used were human studies published from January 1, 2000 to February 20, 2016, in English. There were no restrictions applied on study population nationality, publication type or methodology utilized.

The first 20 pages of a Google Scholar search applying the advanced search command terms 'cost', 'lifetime', 'child', 'adolescent', 'overweight' and 'obesity' were also searched, as well as grey literature using publically available databases or national agency websites known to the authors of this review.

Eligibility criteria

An inclusion and exclusion table for the screening of the initial database review was developed (Table 1).

A reference list search was also conducted of all eligible papers and full texts to identify additional literature. An independent arbitrator made a final decision in case of discrepancies between the findings of the two researchers.

Summary output

The key outcome measure was 'additional lifetime cost, in Irish 2014 Euros, per overweight and/or obese child/adolescent compared to normal weight child/adolescent of the same age'. Key cost estimates from studies were translated into Irish euro for the relevant year, using OECD PPPs (16), and then inflated to 2014, using tables on Consumer Price Index (CPI) from the Central Statistics Office (CSO) in Ireland (17).

Costing methodology

Costs in the literature tend to be presented in the national currency for a specific year. It would therefore be expected that the units of cost will vary between almost all of the studies identified. In order to standardize these for the sake of comparability, they need to be translated into one currency for one particular year. In this review, it was decided to use Irish euro as the currency and 2014 as the year.

In order to do this, key estimates from studies on direct costs and costs because of workdays lost were first translated into Irish euro for the relevant year, using OECD PPPs (16). The general conversion rates were used rather than the specific health rates, as indirect (productivity) costs formed the greater part of the overall costs rather than direct (health care) costs. These costs were then inflated to 2014 Irish euros, using CPI tables from the CSO (17).

Direct costs can therefore be represented by the following equation:

Table 1 Inclusion/exclusion criteria

Task component	Inclusion criteria	Exclusion criteria
Period	Paper published after 2000	Paper published before 2000
Population	All obese and overweight children and adolescents (aged 0–18 years)	Population was not overweight or obese in childhood or adolescence Only a subset of obese and overweight children or adolescents considered (e.g. children with a specific condition)
Comparative groups	Obese and overweight children or adolescents compared with normal weight children or adolescents	Does not compare with normal weight children or adolescents
Type of studies	Need to be able to estimate cost per capita or cost per case relative to normal Human studies *Lifetime or projected total life direct and/or indirect cost (only applied at abstract and full article review stage)**	Unable to deduct cost per case Intervention Studies Animal studies *Does not consider lifetime costs or total life projected costs (e.g. focus is on current annual costs only)**

*This final criterion regarding lifetime costs was added at abstract and full text review, in order to ensure that the papers addressed lifetime costs. Italics here merely indicate part that refers to table footnote (*).

$$\begin{aligned}\text{Cost in Irish 2014 euro} =& (\text{Cost in national currency in year Y})\\ &\times(\text{PPP factor between two countries in year Y})\\ &\times(\text{Irish CPI factor from year Y to 2014}).\end{aligned}$$

Lifetime income penalty was calculated by multiplying the percentage income loss, as provided by the individual studies, by the average income in euro per individual for the second quarter of 2014 in Ireland, acquired from the CSO database (17). This was multiplied by 40 as a typical lifetime period of work to generate the full lifetime income penalty. No discounting was applied.

This can be represented by the following equation:

$$\begin{aligned}\text{Lifetime Income Penalty} =& (\text{Percentage income loss})\\ &\times(\text{Average annual income in Ireland, Q2 2014})\\ &\times 40.\end{aligned}$$

In order to avoid double-counting when deducing total productivity costs, costs because of workdays lost were reduced by the percentage income loss.

Costs because of workdays lost can therefore be represented by the following equation:

$$\begin{aligned}\text{Cost in Irish 2014 euro} =& (\text{Cost in national currency in year Y})\\ &\times(\text{PPP factor between two countries in year Y})\\ &\times(\text{Irish CPI factor from year Y to 2014})\\ &\times[1-(\text{Income loss})].\end{aligned}$$

Results

Study selection

Search of the databases revealed 3,998 papers, of which 535 were duplicates and removed. The remaining 3,463 study titles were screened using all the eligibility criteria except the last one referring to lifetime costs (Table 1). A number of key studies used the perspective of an overweight and/or obese 20-year old, and because it was considered unlikely that these study populations would be substantially different from those of studies that used the perspective of overweight and/or obese 18-year olds, it was decided to also include these studies (18–20). With these criteria, 3,314 titles were excluded, mainly because the study population was not overweight or obese in childhood or adolescence, or only a subset of obese and overweight children or adolescents were considered. The abstracts of the resulting 149 were then screened, now also adding the final inclusion criteria that studies should estimate lifetime excess costs. A further 125 papers were thus excluded, and 24 articles were exposed to full text review. Following arbitration by an independent arbitrator, a further 12 papers were then excluded for a variety of reasons including that the studies were actually trials of obesity interventions where baseline lifetime costs were acquired from another study, that studies were not estimating lifetime costs and that costs were for a subset of children only. This resulted in 12 papers for review, with one more paper added as a result of reference list searching. No additional papers were found by Google Scholar search or searching grey literature. A search of the Cochrane database did not elicit any reviews. The final number of papers included for review in this paper was therefore 13. The search is summarized in Figure 1.

The majority of the studies (eight in all) was conducted in the USA, with just five from Europe (two from Germany, two from Sweden and one from the Netherlands). Most studies (eight) examined direct costs only (18–25). Four examined indirect costs, of which two addressed costs because of workdays lost (26,27) and two looked at income penalty (28,29). Just one examined both direct and indirect costs (workdays lost only) (30). Three studies were observational

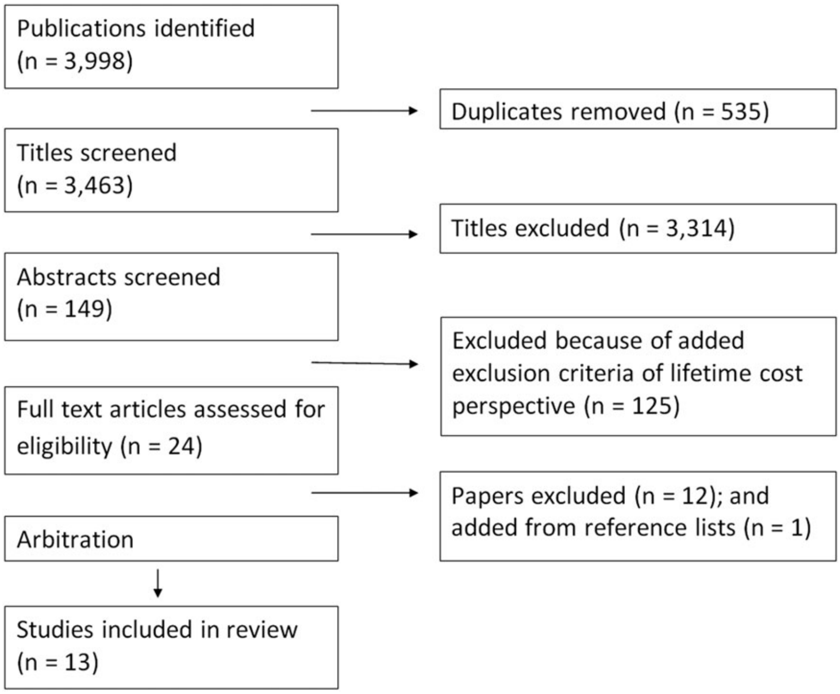

Figure 1 Search summary.

longitudinal cohorts and 10 used forecast modelling (six cohort models, one micro-simulation and three macro-simulations). The key features and findings of each study are summarized in Table 2.

Excess lifetime direct costs

None of the studies addressing direct costs used observational longitudinal cohorts. Moreover, there was significant variability in the modelling used and the subcategories of cost incorporated. These variations include the age at which it is assumed that excess costs start to accumulate, e.g. whether costs during childhood/adolescence are included or not. Two of the eight studies identified modelled direct costs incurred during childhood (22,24). There is also significant variation in the methods for calculating costs and cost components. Some allow transitions in BMI over time while others keep the same BMI status throughout the lifecycle. The age at which the weight status of the study populations is considered also varies significantly. Unfortunately, there are also differences in what benchmarks are used for defining overweight and obesity in children and adolescents. All these findings are summarized in Table 2. A table with further information on each study is available on request to the corresponding author, and a spread-sheet of calculations is available as an on-line supplement (Figure S1 in Supporting information).

After converting values into Irish 2014 euros, the range of excess direct lifetime costs for studies conducted in the USA is between −€4,201 and €3,410 for male children/adolescents with overweight and between −€367 and €8,422 for female children/adolescents with overweight (Table 2). For the population with obesity grade I, these ranges are from €10,328 to €17,104 and €14,240 to €22,352 for boys and girls, respectively. For those with obesity grade II/III, the ranges are between €17,342 and €17,692 and €26,858 and €30,556, respectively. When the degree of obesity is not given, the range lies between €6,580 and €35,810 for boys and between €8,016 and €45,283 for girls. The costs for grade I obesity and grade II/III obesity thus fall appropriately within the cost range of non-specified obesity. Direct costs per adolescent with obesity had to be deduced from the data in one US study that only presented cumulative excess national costs, amounting to $254 billion: $208 billion because of work-days lost and $46 billion from direct medical costs (30). The estimate of €8,626 was calculated by applying a 17% prevalence rate of obesity (as given in the paper) on the US Census 2000 12-year-old to 19-year-old population of approximately 32.5 million (31). This study did not disaggregate by gender, but the estimate is just above the lower limits of both the male and female cost ranges given above.

Only two studies looked at excess direct lifetime costs in Europe. One used the perspective of a 20-year old and did not differentiate by sex or degree of obesity, and the other only presented the costs of children with overweight and obesity as a total. van Baal et al. estimated that the lifetime excess direct costs were −€41,401 for 20-year olds

Table 2 Summary of findings for key parameters of each paper

First author, year	Country	Types of cost included	Type of model	BMI change allowed	Age ranges covered (years)	Comparative groups	Key outcome measure in Irish euro, 2014 and (original currency, year)	Other findings/ comments
Lightwood, 2009 (30)	USA	Direct (hospital in-patient CHD and DM only) and indirect (workdays lost)	Cohort Model: Coronary Heart Disease Policy Model	Yes	Weight (12–19); Costs (35–64)	Obese adolescent (>95th percentile; US-CDC) vs. normal weight adolescent.	€44,626 ($45,921, 2007) in total: €36,000 ($37,605) indirect; €8,626 ($8,316) direct.	Median wage served as a measure of per person money compensation because obesity is concentrated at the lower end of the income distribution. Cumulative excess total costs in USA are estimated at $254 billion: $208 billion because of lost productivity and $46 billion from direct medical costs, 2007 values, 3% annual discount rate.
Amis, 2014 (28)	USA	Indirect (income penalty) earnings from Add Health survey	Observational longitudinal cohort	N/A	Weight (12–18); Follow-up (25–31)	Obese 12-year to 18-year old (>95th percentile) Vs non-obese. (probably US-CDC, not stated) Reported BMI.	25-year-old to 31-year-old adults who were obese adolescents earned 7.5% less (men: 6.0%; women: 8.7%; White people: 5.7%).	Results suggest that loss of earnings is mediated through reduced likelihood of obtaining a college degree.
Lundborg, 2014 (29)	Sweden	Indirect (income penalty); annual earnings taken from tax records	Observational longitudinal cohort military service, Males only	N/A	Weight (18) follow-up (28–38)	Overweight (BMI: 25–29.9) and obese adolescent (BMI: 30+) vs. normal weight adolescent; measured BMI.	Loss in earnings: 7.4% and 2.9% for obese and overweight, respectively. Non-adjusted estimates of 18% and 7%, respectively.	Adjusted for cognitive skills at age 18, sibling effects and parental characteristics. Additional analyses using data sets from the United Kingdom and the United States gave similar results. Study suggests that the mechanism of the penalty operates through lower skill acquisition and ' occupational sorting'.
Neovius, 2012 (26)	Sweden	Indirect (workdays lost) human capital approach	Observational longitudinal cohort military service, men only	N/A	Weight (18); productivity (18–56) extrapolated to (65)	Overweight (BMI > 25) and obese (BMI > 30) vs. normal weight adolescent.	€15,941 (SEK163,600, 2010) for overweight; €35,859 (SEK383,000) for obese.	Using 3% discount rate; inflated to year 2010 Swedish Kronor. Premature death accounted for €6,470 (SEK64,475) and €26,073 (SEK259,824), respectively. Friction cost method (absent workers assumed to be replaced after 6 months): overweight €3,500; obese €6,000.
Sonntag, 2016 (27)	Germany	Indirect (workdays lost) human capital approach	Two-stage Markov cohort state transition model	Yes	Weight (3); costs begin at (18)	Overweight plus obese vs. normal weight child (based on national reference curves).	€4,313 (€4,209, 2010) for boys and €2,451 (€2,445) for girls.	Discounted (3%). Proportion occurring before age 60: 0.81 (boys) and 0.79 (girls).
Fernandes, 2010 (21)	USA	Direct (Medical Expenditures Panel	Monte-Carlo micro-simulation	Yes	Weight (6–11); costs begin at (9) or (30)	Obese child (>95th percentile; probably US-CDC, not stated)	€11,837 ($12,047, 2008) for boys and €15,366 ($15,639) for girls,	$8,399 for men and $9,812 for women, assuming excess costs begin at age 30; discount rate: 3%; 2008 values;

(*Continues*)

Table 2 (Continued)

First author, year	Country	Types of cost included	Type of model	BMI change allowed	Age ranges covered (years)	Comparative groups	Key outcome measure in Irish euro, 2014 and (original currency, year)	Other findings/ comments
		Survey [MEPS]: household only)				vs. normal weight child.	assuming excess costs begin at age 9.	adjusted for life expectancy. Self-reported BMI. See Finkelstein (2008) below for cost types included in MEPS (excludes spending on vision and dental care).
Finkelstein, 2008 (18)	USA	Direct (MEPS, costs: hospital, physician, home health care providers and pharmacies)	Macro-model: logistic regression	No	Weight (20); Costs begin at (20)	Overweight (BMI: 25–29.9), obese I (BMI: 30–34.9), and obese II/III (BMI: >35) 20 y/o adults vs. normal weight 20 y/o adult.	Overweight: men €0, women €8,422 ($8,120, 2007); obese I: men €17,104 ($16,490), women €22,352 ($21,550); obese II/III: men €17,342 ($16,720), women €30,556 ($29,460).	Logistic regression to estimate differences in probability of utilization by obesity status; generalized linear model (GLM) with log link function and gamma family distribution of the error term used to estimate differences in expenditures among those using any care. Lifetime costs from a societal a private employer or insurer's perspective, and from a Medicare perspective, inflated to 2007 values. Discounted at 3% and adjusted for life expectancy. Self-reported BMI.
Ma, 2011 (22)	USA	Direct (MEPS). See Finkelstein (2008) above	Macro-model: logistic regression	No	Weight (0–6); costs begin at (6)	Obese child (> 95th percentile; US-CDC) and obese adult (BMI > 30) vs. normal.	Men: €35,810 ($32,320, 2006); women: €45,283 ($40,870).	In 2006 values discount rate 3%, authors estimate that for every 1% reduction in obesity rates, at ages 0–6, 7–12 and 13–18, cost-effective to spend up to $2,375, $1,648 and $1,924 per child, respectively. See Finkelstein (2008) above for details on logistic regression and GLM and also on cost types included in MEPS.
Sonntag, 2015 (23)	Germany	Direct (in and outpatient treatment, rehab, health protection, ambulance, admin, research, education, investments)	Two-stage Markov cohort state transition model	Yes	Weight (3); costs begin at (18)	Overweight plus obese vs. normal weight child (based on national reference curves).	Boys: €4,680 (€4,262, 2010). Girls: €7,718 (€7,028).	Discounted (3%). Estimated excess costs for a large number of obesity-related diseases, e.g. type 2 diabetes, hyperlipidaemia, hypertension, coronary heart disease, digestive diseases and certain type of cancers.
Trasande, 2010 (24)	USA	Direct MEPS. Also assumes $50,000 per QALY lost	Cohort simulation model	Yes	Weight (12); costs begin at (12)	Obese (>95th percentile) (US-CDC) and overweight (>85th percentile) vs. normal weight child.	Obese: men €6,580 ($5,645, 2005); women €8,016 ($6,877). Overweight: men €3,410 ($2,925); women €3,730 ($3,200).	3% discount rate, 2005 values. During childhood (up to age 18), US children who were age 12 in 2005 are estimated to incur $2.77 billion in attributable medical expenses. Obese adults will incur $3.47 billion in additional medical

(*Continues*)

Table 2 (Continued)

First author, year	Country	Types of cost included	Type of model	BMI change allowed	Age ranges covered (years)	Comparative groups	Key outcome measure in Irish euro, 2014 and (original currency, year)	Other findings/ comments
								expenditures because they were obese or overweight as children, and 2,102,522 QALYs will be lost as a result of elevations in childhood BMI. Overweight costs mainly accrue in childhood, obesity costs in adulthood.
Tucker, 2006 (19)	US	Direct (derived from published sources)	Semi-Markov Cohort model	Yes	Weight (20): costs begin at (20)	Obese III (BMI = 44) and obese I (BMI = 34) vs. normal weight (BMI = 24).	Men: BMI 34 vs. 24, €10,328 ($8,704, 2004); BMI 44 vs. 24, €17,692 ($14,910). Women: BMI 34 Vs 24, €14,240 ($12,001); BMI 44 Vs 24, €26,858 ($22,634).	Discounted at 3% per annum. Model entailed total direct costs were increased by 2.3% for each BMI unit above 25, and by 1.3% for each year increase in age.
van Baal, 2008 (20)	The Netherlands	Direct. Not specified	Deterministic Markov Cohort model	No	Weight (20); costs begin at (20)	Obese (BMI > 30) vs. normal weight.	Lifetime health expenditure was €41,401 (€31,000, 2003) higher for a normal weight than an obese 20-year old.	Differences in life expectancy (e.g. healthy weight non-smokers were estimated to live for an additional 4.5 years) and inclusion of costs and diseases not related to obesity entail an increase in the lifetime costs of normal weight cohort. Discount rates of 3% and 4% applied. 2003 values.
Wang, 2010 (25)	USA	Direct (MEPS). See Finkelstein (2008) above	Macro model, logistic regression	No	Weight (16–17); costs begin at (40)	Obese (BMI > 95th percentile) and overweight (>85th BMI <95th percentile) vs. normal weight adolescents.	Obese: boys €10,690 ($10,307, 2007); girls €9,880 ($9,526). Overweight: boys −€4,201 (−$4,050); girls: −€367 (−$354).	2007 values discounted at 3% to age 17 years. Self-reported BMI. See Finkelstein (2008) above for details on logistic regression and GLM.

Add Health, National Longitudinal Survey of Adolescent Health; BMI, body mass index; CHD, coronary heart disease; QALY, quality-adjusted life years.

with obesity compared with 20-year olds with normal weight (20), and Sonntag et al. estimated a total €4,680 in direct costs for boys with obesity and overweight and €7,718 for girls with obesity and overweight (23), after conversion of the estimates given in both papers into 2014 Irish euros.

Excess lifetime indirect costs

We looked at costs because of both workdays lost and income penalty. Three studies looked at costs because of workdays lost of which two were European and one American. These costs were presented in one European study as €15,941 and €35,859 per male adolescent with overweight and obesity respectively (26) and in another as €2,451 and €4,313 per female and male child, respectively, with both overweight and obesity (27). Lifetime excess costs from workdays lost per individual was deduced from the American study in a similar manner to that explained above relating to direct costs, resulting in a €36,000 lifetime cost per adolescent with obesity (30). None of these studies looked at costs because of presenteeism.

Two studies looked at adolescent obesity and income penalty, one from the US (28), the other from Sweden (29). The percentage income penalties reported did not take into account work days lost. The US study used the National Longitudinal Survey of Adolescent Health and estimated that 25-year-old to 31-year-old adults who had been adolescents with obesity earned 7.5% less than their counterparts who had not been with obesity as adolescents (men: 6.0%; women: 8.7%; White people only: 5.7%). The Swedish study, which looked at tax records of men only, estimated that 18-year olds with obesity stood to earn 18% less while 18-year olds with overweight would earn 7% less than their normal weight counterparts, falling to 7.4% and 2.9% for obesity and overweight, respectively, when adjusting for cognitive skills at age 18, sibling effects and parental characteristics. The Swedish study moreover demonstrated that using available data from the United States and the United Kingdom would result in similar unadjusted values, demonstrating generalizability (29). If the average annual income per individual in Ireland for Quarter 2 of 2014 of €36,238 is used (32) and an average lifetime years of paid work is assumed to be 40 years, the resulting lifetime income penalty drawn from the results of the two studies would range from €86,971 to €107,264 per male adolescent with obesity, be €126,108 per female adolescent with obesity and €42,036 per male adolescent with overweight.

Quality of studies

A recent systematic review by Dee et al. of the cost of obesity concluded that internationally agreed quality standards on methods for cost of obesity studies are required to improve the availability of quality evidence and to facilitate comparability of data (12). We were guided by the three broad criteria for evaluating the quality of modelling in the International Society for Pharmacoeconomics and Outcomes Research guidelines assessing model structure, data used as inputs to models and model validation (33).

Although macro-models are considered more appropriate for short-term projections (14), three direct cost studies used this type of modelling (18,22,25). This may explain the large inter-study differences in the estimates generated from these studies (€10,690 to €35,810 for obesity in men). Five of the studies used the Medical Expenditure Panel Survey (18,21,22,24,25) that records household expenditure on hospitals, physicians, home health care providers and pharmacies. The lifetime cost estimates for a male child with obesity generated by these five studies ranged from €6,580 (24) to €35,810 (22). At least part of the reason for the wide range may be that the highest estimate did not account for the normal physiological weight gain through adulthood among normal weight children (22), thus over-estimating the effect of obesity in childhood. Without this study, the upper bound estimate would reduce to about €17,000 (18).

Model validation can be divided into internal (internal testing), external (based on best evidence) and between-model validation (33). Although the models seem to broadly satisfy these validation criteria, they were often not explicitly reported on. The 'semi-Markov model' of Tucker et al. is an exception and remained robust to significant internal testing (19). Briggs et al. highlight in another International Society for Pharmacoeconomics and Outcomes Research report the importance of reporting uncertainty by both deterministic and probabilistic sensitivity analysis (34). Deterministic and/or probabilistic sensitivity analyses were undertaken to assess the robustness of the modelled results in most of the studies. Sensitivity tests were not presented for two of the papers, however (22,28), and only very limited sensitivity analysis in a third (19).

It would be expected in general that longitudinal cohorts generate more accurate data than simulation models because they report on real events. The findings of the longitudinal cohorts (26,28,29) in this review are therefore likely to be of high quality. Discounting was not applied on the future costs generated from the percentage income penalty reported in the two relevant studies (28,29) and although zero growth and inflation from current salary levels were assumed this could be seen as a potential source of upward bias. Measured data is generally more accurate than self-reported data, so the four studies that used measured BMI (23,26,27,29) would be considered of high quality from that perspective. The substantial variation seen in results of simulation studies points at the need for more observational longitudinal studies using measured BMI, with thorough use of standardized sensitivity analysis.

Variations in costs

All studies, except those estimating income penalty, use a discount rate of 3% on future costs. There was not much inter-study variation in lifetime costs for studies estimating the cost of workdays lost. All three studies used similar human capital approaches. One study (26) also estimated the lifetime cost using the friction cost approach, which reduced the estimate from about €36,000 to €6,000 for a male adolescent with obesity. The two studies that estimated income penalty generated very similar results.

The main inter-study variability was seen in relation to direct cost estimates. Because it is likely that it is an important determinant of final estimates, we looked at the type of costs included in the analysis of each study. One study, using hospital costs for obesity related diabetes mellitus and coronary heart disease only, generated a lifetime cost in the lower part of the range at €8,626 per obese adolescent (30). The German study that included more direct cost types than any other study (in-patient and out-patient hospital treatment, rehabilitation, health protection, ambulance services, administration, research, education and investment costs) only generated a lifetime cost of €4,680 per male child, although this related to both overweight and obese children (based on national reference curves) (23). Negative direct costs were reported in two studies, one on estimating lifetime costs for adolescents with obesity (van Baal et al.) (20) and the other with overweight (Wang et al.) (25). The authors of the latter suggested that one possible reason for overweight individuals having lower costs than their normal weight counterparts might be that many diseases are associated with low BMI, such as cancer and AIDS, resulting in higher medical care costs.

van Baal et al. (20) raise an important issue regarding how directs costs should be calculated. They estimate that obesity in adolescence leads to significant lifetime healthcare cost savings, as early (and sudden) death because of obesity-related morbidity such as ischaemic heart disease entails considerable health service savings on costs for other conditions, including non-obesity related ones, which would otherwise have been generated. Their model is therefore unique in including conditions explicitly unrelated to obesity. Lifetime health expenditure was highest among healthy-living adolescents and lowest for smokers in their study, with individuals with obesity holding an intermediate position. Because the life-years gained from a healthy lifestyle are not all lived in full health, major public health threats like smoking and obesity may save on direct healthcare costs in the long run more than they cost in the short run. This study is an outlier both in terms lifetime cost estimate and methodology, but provides important information on potential costs from an overall healthcare perspective.

Direct costs seem to be higher in the US than Europe, whereas costs because of workdays lost and income penalty are similar in the two regions, probably reflecting higher healthcare costs in the USA. We argue that from a welfare economic viewpoint, the societal perspective is most relevant. The finding that lifetime indirect costs of childhood/adolescent obesity are greater than direct costs therefore highlights the need to include indirect costs in any lifetime cost study. The need to include indirect costs is brought out particularly strongly by the paper by van Baal et al. (20). Early mortality entails proportionally greater costs because of workdays lost, with two thirds of productivity costs accruing from premature death according to one study (26). This suggests that the greater the direct cost savings are, the greater the indirect costs will become. van Baal et al. acknowledge that they have ignored broader cost categories and consequences of obesity to society, and that indirect costs omitted from their study could well have been higher than the direct medical costs they estimated. With indirect costs being up to five times greater than direct costs (30), it is likely that van Baal et al. (20) would have arrived at very different conclusions had they included indirect costs.

Table 3 summarizes this relationship between total, direct and indirect costs and shows that total lifetime costs are similar for male and female children and adolescents with obesity. It reports the mean value and the range where relevant within each category only of studies that provide lifetime cost estimates for male and/or female children with obesity and/or overweight. The estimates generated by three studies are therefore not included in this table as they do not

Table 3 Summary of total lifetime excess cost in Irish 2014 euro per overweight or obese child/adolescent

Cost	Boys with obesity (€)		Overweight (€)		Girls with Obesity (€)		Overweight (€)	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Direct	6,580 to 35,810	16,229	−4,201 to 3,410	−264	8,016 to 45,283	19,636	−367 to 8,422	3,928
Indirect								
Workdays lost		35,859		15,941		2,451	No data	No data
Income penalty	86,971 to 107,264	97,118		42,036		126,108	No data	No data
Subtotal	122,830 to 143,123	132,977		57,977		128,560		
TOTAL	129,410 to 178,933	149,206	53,776 to 61,387	57,713	136,576 to 173,842	148,196		

segregate costs along these categories, although they are discussed separately (20,23,30).

This work has revealed that there are a large number of significant challenges in the review of evidence on lifetime costs of childhood obesity, particularly relating to methods in estimating direct costs, making valid comparisons between studies problematic. These include whether the normal physiological increase in weight in adulthood is accounted for or not and the age at which it is assumed that excess costs start to accumulate in the models. Only two studies of 13 identified modelled direct costs incurred during childhood (22,24). There is also variation in methods for calculating costs and cost components, and what type of direct or indirect costs are included. Moreover, models vary as to whether transitions in BMI status over time are incorporated or not, whether results are differentiated by childhood age of obesity, gender and race/ethnicity. Finally, how overweight and obesity are defined for children, adolescents and adults varies between studies.

Another important consideration in attempting to deduce the total excess lifetime costs of childhood and adolescent overweight and obesity is that there are considerable costs that have not been incorporated to date. Firstly, the costs of routine surgical procedures for those with obesity are often much greater than average costs for these conditions (surgery for patients with obesity carries a greater complication rate and therefore cost) (35). This has not been included in models. Secondly, no studies to date have modelled indirect costs because of obesity during childhood (e.g. time taken off by parents because of their children's obesity related illnesses). Other effects not considered in models include excess costs for normal weight adults who were obese as children/adolescents and that morbidities because of obesity originating from childhood tend to be more severe than those from adult acquired obesity (36). Losses in leisure time, quality of life or losses in the individual's contributions to social life are not included in any study.

Any attempt at deducing the total (indirect and direct) costs is therefore likely to be an underestimate. Nevertheless, a better understanding of the magnitude of the total cost, and the costs in the three key categories that have received attention to date, might be useful for policymakers. If the remit is resource allocation solely within the health sector, then maybe only direct costs are relevant. Income penalty has particular relevance for the individual and may hold additional importance from the perspective of socio-economic equality. All costs must be considered if policy is made from a societal perspective.

Conclusions

This is the first review in the international literature of studies that address the lifetime costs of childhood/adolescent overweight and obesity in both Europe and the US. It is also the first to incorporate and summarize both direct and indirect costs. We conclude that childhood overweight and obesity generate considerable lifetime direct healthcare and indirect productivity costs.

Within these costs, a number of trends are apparent. First, lifetime healthcare costs and income penalty appear greater in girls while costs because of workdays lost seem greater in boys. Second, there is proportionality between BMI and costs, with lifetime costs increasing in proportion with excess weight in childhood or adolescence. Third, productivity costs are significantly greater than healthcare costs.

Most studies only look at direct costs, but this may create an erroneous picture for policy makers. It is essential from a societal perspective to consider both indirect and direct costs in any estimation of total lifetime costs. These total lifetime costs are in the region of €150,000 for both male and female children and adolescents with obesity, with direct costs being only approximately one eighth of this. Although lifetime cost is almost three times greater per child with obesity than per child with overweight, the lifetime cost to society of the whole child cohort may be greater for the overweight than for the obese, depending on the respective prevalence rates. The total lifetime costs reported here are likely to be under-estimates because there are also numerous costs not captured in the literature to date, such as presenteeism in adulthood and indirect costs incurred during childhood. These gaps indicate the need for further research into the total excess lifetime costs of childhood and adolescent overweight and obesity. Finally, studies that project lifetime direct costs from current childhood overweight and obesity rates need to better abide by internationally agreed standards, such as those of the International Society for Pharmacoeconomics and Outcomes Research, in order to enable more robust quality assessment and inter-study comparability.

Conflict of interest statement

Dr Hamilton reports personal fees from *safefood* Ireland/UCC during the conduct of the study. Dr Perry reports grants from *safefood* Ireland during the conduct of the study. Dr Dee has nothing to disclose.

Acknowledgements

The work on this paper is part of a larger study on the lifetime costs of childhood overweight and obesity on the island of Ireland, supported by *safefood* Ireland. Special thanks go to Jude Cosgrove who undertook the duplicate search and Kevin Balanda who provided input for the methodology and assisted in the search process. The authors would like to acknowledge the support and input of all the members of the study group on this paper including Edel Doherty, Laura

McCarthy, Grace O'Malley, Fiona Geaney, Lorraine Fahy, Michelle Queally and Laura Carter.

Supporting information

Additional Supporting Information may be found online in the supporting information tab for this article. https://doi.org/10.1111/obr.12649

Figure S1. Supporting Information

References

1. Sassi F. The social dimensions of obesity. In: Sassi F (ed.). In association with the Organisation for Economic Co-operation and DevelopmentObesity and the Economics of Prevention: Fit Not Fat. Elgar: Cheltenham, U.K. and Northampton, Mass, 2010, pp. 79–106.
2. World Health Organisation/Europe approaches to obesity [http://www.euro.who.int/en/health-topics/noncommunicable-diseases/obesity/obesity]
3. Mathers CSG, Mascarenhas M. Global health risks: Mortality and burden of disease attributable to selected major risks. *World Health Organisation* 2009: 11–12.
4. Organisation for Economic Co-operation and Development. Health at a Glance 2015: OECD Indicators. OECD Publishing, 2015.
5. WHO Fact sheet: obesity and overweight [http://www.who.int/mediacentre/factsheets/fs311/en/]
6. Wirtz VJ. Update on Background Paper 6.18 Obesity. In: Priority Medicines for Europe and the World. World Health Organisation, 2012.
7. Extended international (IOTF) body mass index cut-offs for thinness, Overweight and Obesity in Children [http://www.worldobesity.org/resources/child-obesity/newchildcutoffs/]
8. Hollingworth W, Hawkins J, Lawlor DA, Brown M, Marsh T, Kipping RR. Economic evaluation of lifestyle interventions to treat overweight or obesity in children. *Int J Obes* 2012; **36**(4): 559–566.
9. DATAGRAPHIC. In. *Health Aff* 2015; **34**: 1808–1809.
10. Obesity: Data and statistics: World Health Organisation; 2016.
11. Finklestein EA, DiBonaventura M, Burgess SM, Hale BC. The costs of obesity in the workplace. *J Occup Environ Med* 2010; **52**.
12. Dee A, Kearns K, O'Neill C *et al*. The direct and indirect costs of both overweight and obesity: a systematic review. *BMC Res Notes* 2014; **7**(1): 1–9.
13. Sargent JD, Blanchflower DG. Obesity and stature in adolescence and earnings in young adulthood. An analysis of a British birth cohort. *Arch Pediatr Adolesc Med* 1994; **148**: 681–687.
14. Astolfi R, Lorenzoni L, Oderkirk J. A comparative analysis of health forecasting methods. *OECD Health Working Papers* 2012; **59**.
15. Finkelstein EA, Wan Chen Kang G, Malhotra R. Lifetime Direct Medical Costs of Childhood Obesity. *Pediatrics* 2014; **133**(5): 854–862 859p.
16. Purchasing power parities (PPP) [http://www.oecd-ilibrary.org/finance-and-investment/purchasing-power-parities-ppp/indicator/english_1290ee5a-en?isPartOf=/content/indicatorgroup/067eb6ec-en]
17. Annual percentage change in consumer price index (%) by year and commodity group [http://www.cso.ie/quicktables/GetQuickTables.aspx?fileName=CPA01C4.asp&TableName=Annual+Percentage+Change&StatisticalProduct=DB_CP]
18. Finkelstein EA, Trogdon JG, Brown DS, Allaire BT, Dellea PS, Kamal-Bahl SJ. The lifetime medical cost burden of overweight and obesity: implications for obesity prevention. *Obesity (Silver Spring, Md)* 2008; **16**(8): 1843–1848.
19. Tucker DM, Palmer AJ, Valentine WJ, Roze S, Ray JA. Counting the costs of overweight and obesity: modeling clinical and cost outcomes. *Curr Med Res Opin* 2006; **22**(3): 575–586.
20. van Baal PH, Polder JJ, de Wit GA *et al*. Lifetime medical costs of obesity: prevention no cure for increasing health expenditure. *PLoS Med* 2008; **5**(2): e29.
21. Fernandes M-M. Estimating the lifecycle costs associated with childhood obesity in evaluating the impacts of school nutrition and physical activity policies on child health *Policy Analysis*. RAND Corporation, 1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407–2138: Pardee RAND Graduate School; 2010.
22. Ma S, Frick KD. A simulation of affordability and effectiveness of childhood obesity interventions. *Acad Pediatr* 2011; **11**(4): 342–350.
23. Sonntag D, Ali S, Lehnert T, Konnopka A, Riedel-Heller S, König HH. Estimating the lifetime cost of childhood obesity in Germany: results of a Markov Model. *Pediatric obesity* 2015.
24. Trasande L. How much should we invest in preventing childhood obesity? *Health Aff* 2010; **29**(3): 372–378.
25. Wang LY, Denniston M, Lee S, Galuska D, Lowry R. Long-term health and economic impact of preventing and reducing overweight and obesity in adolescence. *J Adolesc Health* 2010; **46**(5): 467–473.
26. Neovius K, Rehnberg C, Rasmussen F, Neovius M. Lifetime productivity losses associated with obesity status in early adulthood: a population-based study of Swedish men. *Appl Health Econ Health Policy* 2012; **10**(5): 309–317.
27. Sonntag D, Ali S, De Bock F. Lifetime indirect cost of childhood overweight and obesity: a decision analytic model. *Obesity* 2016; **24**(1): 200–206.
28. Amis JM, Hussey A, Okunade AA. Adolescent obesity, educational attainment and adult earnings. *Appl Econ Lett* 2014; **21**(13–15): 945–950.
29. Lundborg P, Nystedt P, Rooth D-O. Body size, skills, and income: evidence from 150,000 teenage siblings. *Demography* 2014; **51**(5): 1573–1596.
30. Lightwood J, Bibbins-Domingo K, Coxson P, Wang C, Williams L, Goldman L. Forecasting the future economic burden of current adolescent overweight: an estimate of the coronary heart disease policy model. *Am J Public Health* 2009; **99**(12): 2230–2237.
31. U.S. Summary: 2000; Census 2000 Profile. U.S. Department of Commerce, Economics and Statistics Administration: US Census Bureau; 2002.
32. Earnings and Labour Costs Quarterly [http://www.cso.ie/en/releasesandpublications/er/elcq/earningsandlabourcostsq12016final q22016preliminaryestimates/]
33. Weinstein MC, O'Brien B, Hornberger J *et al*. Principles of good practice for decision analytic modeling in health-care evaluation: report of the ISPOR Task Force on Good Research Practices—Modeling Studies: report of the ISPOR Good Research Practices Task Force. *Value Health* 2003; **6**(1): 9–17.
34. Briggs AH, Weinstein MC, Fenwick EAL, Karnon J, Sculpher MJ. Paltiel AD, on behalf of the ISPOR-SMDM Modeling Good Research Practices Task Force: model parameter estimation and uncertainty: a report of the ISPOR-SMDM Modeling Good Research Practices Task Force-6. *Value inHealth* 2012; **15**: 835–842.
35. Bamgbade OA, Rutter TW, Nafiu OO, Dorje P. Postoperative complications in obese and nonobese patients. *World J Surg* 2007; **31**(3): 556–560.
36. Park MH, Falconer C, Viner RM, Kinra S. The impact of childhood obesity on morbidity and mortality in adulthood: a systematic review. *Obes Rev* 2012; **13**(11): 985–1000.