Estimating the effects of preventive and weight-management interventions on the prevalence of childhood obesity in England: a modelling study

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Summary

Background The effects of the systematic delivery of treatments for obesity are unknown. We aimed to estimate the potential effects on the prevalence of childhood obesity of systematically offering preventive and treatment interventions to eligible children in England, based on weight or health status.

Methods For this modelling study, we developed a cross-sectional simulation model of the child and young adult population in England using data from multiple years of the Health Survey of England conducted between Jan 1, 2010, and Dec 31, 2019. Individuals were assessed for eligibility via age, BMI, and medical complications. Weight status was defined based on clinical criteria used by the UK National Institute of Health and Care Excellence. Published systematic reviews were used to estimate effect sizes for treatments, uptake, and completion for each weight-management tier. We used all available evidence, including evidence from studies that showed an unfavourable effect. We estimated the effects of two systematic approaches: a staged approach, in which children and young people were simultaneously given the most intensive treatment for which they were eligible, and a stepped approach, in which each management tier was applied sequentially, with additive effects. The primary outcomes were estimated prevalence of clinical obesity, defined as a BMI ≥98th centile on the UK90 growth chart, and difference in comparison with the estimated baseline prevalence.

Findings 18 080 children and young people were included in the analytical sample. Baseline prevalence of clinical obesity was estimated to be 11·2% (95% CI 10·5 to 11·8) for children and young people aged 2–18 years. In modelling, we estimated absolute decreases in the prevalence of obesity of 0·9% (95% CI 0·1 to 1·8) for universal, preventive interventions; 0·2% (0·1 to 0·4) for interventions within a primary-care setting; 1·0% (0·1 to 2·1) for community and lifestyle interventions; 0·2% (0·0 to 0·4) for pharmaceutical interventions; and 0·4% (0·1 to 0·7) for surgical interventions. Staged care was estimated to result in an absolute decrease in the prevalence of obesity of 1·3% (–0·3 to 2·4) and stepped care was estimated to lead to an absolute decrease of 2·4% (0·1 to 4·8).

Interpretation Although individual effect sizes for prevention and treatment interventions were small, when delivered at scale across England, these interventions have the potential to meaningfully contribute to reducing the prevalence of childhood obesity.

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Introduction

Childhood obesity in the UK and elsewhere is highly prevalent, causing a substantial burden of illness with associated costs to health-care services.[1,2] Children and young people (ie, aged 2–18 years) with obesity are often exposed to stigmatisation, further affecting their wellbeing. Once established, obesity often continues through adolescence and into adulthood, in which it is associated with cardiovascular diseases and psychosocial comorbidities.[3–5]

There are systemic and structural drivers of childhood obesity that interact to create obesogenic environments and behaviours. Upstream determinants of childhood obesity include the economic, political, and sociocultural environment and the influence of food and built environments.[6] There are substantial inequalities in obesity, which are likely to be exacerbated by the global cost-of-living crisis; families with low income are pressured into buying cheaper, energy-dense foods instead of less affordable, healthier options.[7] Although addressing the systemic drivers of childhood obesity is important, preventing and treating it through weight management remains a public health and policy priority. Weight management is the identification of obesity in children and young people with a subsequent referral to adapted interventions that consider individual factors, such as weight-related comorbidities.[8] In England, the systematic referral to and use of appropriate weight-management interventions is poor.[9] Clinical treatments are frequently perceived to be either ineffective (due to small effect sizes), expensive, or inappropriate (due to concerns about intensive treatments administered

Research in context

Evidence before this study

There are a range of preventive and treatment options to reduce excess weight in childhood. Individually, the effects of preventive and weight-management interventions might be small, but the collective effects of providing these interventions at scale is unknown. On June 7, 2022, we conducted a literature search of PubMed and Google Scholar to identify any studies, published in English from database inception to June 6, 2022, that explored the potential effects on childhood obesity of systematically delivering preventive and weight-management interventions for all eligible children and young people (ie, aged 0–18 years). We used the search terms ("child" OR "adolescent") AND ("obesity" OR "weight" OR "BMI" OR "body mass index") AND ("prevention" OR "intervention" OR "weight management") AND ("modelling" OR "scale" OR "population effects" OR "extrapolation"). To be included, studies had to consider the population-wide effects of child-weight management interventions either individually or in combination. There were no restrictions on the country where studies were conducted, but only English language publications were considered. We only included studies with an outcome of population prevalence of obesity; studies with other outcomes, such as economic outcomes or health-care costs, were excluded. Citation searching of relevant studies was also done. We found studies that estimated the potential effect of weight-management interventions on childhood obesity prevalence and modelling studies that estimated the effect of population-wide policies, such as fiscal interventions, on the prevalence of childhood obesity. Although we found evidence from meta-analyses of trials that both preventive and treatment interventions that were provided to individual children were effective at reducing bodyweight, we could not find any studies from any country that had estimated the effects on the prevalence of childhood obesity of systematically providing these interventions to all eligible children.

Added value of this study

Our study simulated preventive and weight-management interventions by adjusting BMI Z scores according to mean effect sizes and standard deviations with the best available data on the effectiveness and uptake of interventions. We found that systematically providing preventive and treatment interventions to all eligible children in England, in line with national guidelines, could reduce the prevalence of obesity (ie, ≥98th centile on the UK90 growth chart) by 21·4%, equivalent to a 2·4 percentage-point reduction from 11·2% to 8·8%, in the best-case scenario. The most important single intervention contributing to a reduction in obesity was a universal, preventive intervention. Our results show that although effect sizes for preventive and treatment interventions were small or modest at the individual level, when delivered at scale across the population of England, these interventions have the potential to meaningfully contribute to reducing the prevalence of childhood obesity. To the best of our knowledge, this study is the first to explore the potential population effects of weight-management interventions provided systematically and at scale.

Implications of all the available evidence

Although a wide range of policies are needed to address the underlying structural causes of childhood obesity, our findings suggest that childhood preventive and weight-management services can support efforts to reduce the prevalence of childhood obesity. Our findings also challenge the current staged-care approach to weight management in England and suggest that offering all available treatments in a progressive, stepped way might be more effective than staged care at reducing the overall prevalence of childhood obesity. Future research should consider how best to scale up the delivery of preventive and weight-management interventions, how to integrate different treatment approaches, and the effectiveness of integrated approaches at the individual level.

at young ages). Although effect sizes for weight management from high-quality meta-analyses are typically small (ie, <0·5),[10] relatively small effects at the individual level might be important at the population level if interventions are delivered systematically and at scale.[11]

The UK National Institute of Health and Care Excellence (NICE) provides guidance,[12] which is based on evidence and cost-effectiveness, for the delivery of weight-management services to children and young people who have overweight or obesity. In England, there is a tiered approach to weight-management services, in which the treatment type and intensity offered depend on the severity of obesity and the presence of comorbidities (panel). The effectiveness of different management tiers in reducing the prevalence of obesity has also not been explored; for example, comparing low tiers, which are less effective but have a lower cost per individual and a greater reach, with specialist or clinical tiers, which are more effective but expensive and have a lower reach.

We aimed to estimate, via modelling, the potential contribution of different systematic approaches to providing evidence-based preventive and treatment interventions in reducing the population prevalence of obesity in children and young people in England.

Methods

Study design

For this modelling study, we developed a cross-sectional simulation model of the child and young adult population in England using data from multiple years of the Health Survey of England (HSE)[22] to estimate the number of children aged 2–18 years who were eligible for different tiers of intervention on the basis of NICE guidance. Although local definitions and implementation vary, tier-1 interventions usually include universal services, tier-2 interventions usually include lifestyle interventions, tier-3 interventions usually include specialist services, and tier-4 interventions usually include bariatric surgery.[23] Intervention components might overlap (eg, between health promotion and lifestyle intervention), but the targeting and eligibility criteria for each management tier are distinct. Findings from systematic reviews were used to identify the effects of both preventive and treatment interventions on the prevalence of obesity among children and young people in England. We estimated the effects of each tier of intervention individually and then estimated the effects of interventions combined, either in a staged-care or stepped-care approach.

Data source

Nationally representative, cross-sectional data were obtained from the HSEs conducted between Jan 1, 2010, and Dec 31, 2019. Data from each year were merged to create a model dataset of the population of children and young people aged 2–18 years in England. All children and young people with recorded data for BMI, Indices of Multiple Deprivation (IMD), and ethnicity were included. Interview weights that were calculated for the core sample were applied;[24] BMI Z scores (zBMI) were calculated with UK90 reference charts.[25] Weight status was defined based on clinical criteria used by NICE[8] and centiles of UK90 reference charts as overweight (ie, ≥91st to <98th centile), obese, (ie, ≥98th centile), obese class 2 (ie, ≥99·87th centile), or obese class 3 (ie, ≥99·98th centile).[26] Obesity-related comorbidities were identified from additional data that were collected in the HSE (appendix p 2). Sex data were self-reported; the provided options were male or female.

Participants aged 16 years or older gave oral informed consent for all stages of interviews and for nurse visits, which were part of the HSE; written informed consent was provided for biological measurements (eg, blood samples). For participants aged 15 years or younger, parents gave written or oral consent on behalf of their children and their children gave oral assent for interviews and nurse visits. Children who were asked for assent were given a clear, age-appropriate explanation that was comprehensible rather than comprehensive.

Data were obtained from the UK Data Service with appropriate permissions. Ethics approval for the 2010 HSE was obtained from the Oxford B Research Ethics Committee (reference number 09/H0605/73), for the 2011 and 2012 HSEs was obtained from the Oxford A Research Ethics Committee (10/H0604/56), for the 2013 and 2014 HSEs was obtained from the Oxford A Research Ethics Committee (12/SC/0317), for the 2015 HSE was obtained from the West London Research Ethics Committee (14/LO/0862), and for the 2016–19 HSEs was obtained from the East Midlands Nottingham 2 Research Ethics Committee (15/EM/0254).

Panel: Tiers of obesity management

Tier 1

Universal interventions (eg, prevention of obesity and reinforcement of healthy eating and physical activity) and brief advice.

- Universal, multicomponent interventions to prevent childhood obesity, including promotion of healthy diets and physical activity[13,14]
  - For children younger than 5 years, these interventions were typically in the community, at preschool, or in the home[13]
  - For children aged 5–18 years, these interventions were in schools[14]
- Brief interventions including advice, motivational interviewing, and lifestyle-modification education[15]
  - These interventions are typically delivered in primary-care settings (eg, general practitioner offices or other health-care settings)[15]

Tier 2

Lifestyle weight-management services. We considered multicomponent interventions that included diet, physical activity, and behavioural interventions for the treatment of obesity. We considered preschool (children aged 0–5 years),[16] primary school (children aged 6–11 years),[17] and secondary school (children aged 12–18 years) separately.[18]

- These interventions are typically delivered in the community, outpatient clinics, health-care research clinics, homes, and schools[16–18]

Tier 3

A multidisciplinary, clinically led team approach. We considered licensed pharmaceutical interventions that were available in England (ie, orlistat and liraglutide).[19,20]

- These interventions are typically delivered in secondary-care settings (ie, inpatient and outpatient), flexibly, and in the community[19,20]

Tier 4

Bariatric surgery, supported by a multidisciplinary team both before and after the operation. We considered three types of bariatric surgery that are in use in England (ie, gastric band, sleeve gastrectomy, and gastric bypass).[21]

- This intervention is typically delivered in clinical settings, with aftercare in the community[21]

Interventions, eligibility, and related effect sizes

See Online for appendix

The structure of the four tiers of weight-management services that were assessed in this modelling study was based on NICE guidance and former Public Health England (PHE) definitions after a broad consultation on key issues in commissioning and providing access to an integrated obesity-care pathway in England;[27] the consultation was convened by National Health Service England and PHE and was conducted between local commissioners and national health and social care organisations. We identified an evidence base for two types of tier-1 interventions: universal services and prevention, which are typically delivered in preschools or schools, and brief interventions including advice, which are typically delivered in a primary-care setting by a general practitioner or health practitioner. Tier 2 was multicomponent weight-management interventions, which focus on increasing physical activity and improving healthy eating. These interventions were typically delivered by health-care professionals in outpatient or community settings. Tier 3 was specialist services and pharmaceutical interventions (ie, orlistat and liraglutide), which often also include behavioural interventions. Tier 4 was bariatric surgery.

Eligibility was defined with NICE guidance.[8] We assumed that all children and young people were eligible for tier-1, universal, preventive interventions and that only children with obesity (ie, ≥98th centile calculated with UK90 reference data; equivalent to 2·05 SDs above the mean) were offered brief advice or an intervention in primary care. For tier 2, weight-management services were offered to all children and young people with obesity (ie, ≥98th centile; equivalent to 2·05 SDs above the mean). For tier 3, pharmaceutical interventions were offered to children and young people aged 13–18 years with obesity (ie, ≥98th centile) and an obesity-related comorbidity. For tier 4, surgery was offered to children and young people aged 13–18 years with class 3 obesity (ie, ≥99·98th centile; equivalent to 3·54 SDs above the mean) or class 2 obesity (ie, ≥99·86th centile; equivalent to 3·01 SDs above the mean) with an obesity-related comorbidity.

To identify effect sizes related to each tier, we searched MEDLINE, the Cochrane Library, and Google Scholar for systematic reviews that provided pooled effect sizes from randomised controlled trials (RCTs) of preventive and treatment interventions for childhood obesity. Separate searches were conducted for universal, preventive interventions (tier 1), brief interventions in primary-care settings (tier 1), lifestyle or behavioural interventions in community settings (tier 2), pharmaceutical interventions (tier 3), and surgical interventions (tier 4). Search results were filtered by date and evidence was obtained from the eight most recent systematic reviews and one most recent trial. We used all available evidence; we did not exclude evidence from low-income or upper-middle-income countries, studies that were assessed to be low quality by review authors, or studies that showed an unfavourable effect. For tier 3, we considered evidence from one systematic review with subgroup analysis for each drug type (including orlistat), and one RCT for liraglutide.

Effect sizes were extracted for all available research. Due to the nature of RCT data, effects versus a control group were presented rather than versus baseline. For our model, we used effect sizes from all available evidence given because of a scarcity of evidence for some management tiers. If multiple follow-ups were reported, we used the longest follow-up that was available or the follow-up that included the most data. Age-specific effect sizes were used if data were provided. For pharmaceutical interventions, evidence was obtained for two drugs that are currently licensed and used for weight loss in England (ie, orlistat and liraglutide); pooled effect sizes were available for orlistat but not for liraglutide, so the effect size for liraglutide was derived from an individual trial. We calculated uptake (ie, numbers screened *vs* randomly assigned) and completion (ie, numbers randomly assigned *vs* completed the intervention) rates from studies included in each systematic review if those data were reported (table 1; appendix pp 3–4).

Modelling scenarios and outcomes

We modelled the effect of six scenarios on obesity prevalence; four were single-tier and two were systematic approaches of the tiers. Interventions from each management tier were applied individually to children and young people who were eligible and in combination with both staged and stepped approaches to treatment. In staged care, all children were given the most intensive treatment for which they were eligible; this follows the general approach for cancer care, for example, in which the disease is staged and the most appropriate treatment is offered. In stepped care, each management tier was applied additively in sequence, from the lowest-cost and least-intensive treatments through to higher-cost and more-intensive treatments; this follows the approach for diseases such as depression, in which different treatments are offered in a sequence, proceeding to the next step if previous treatment has not been successful (eg, if previous treatment had not reduced a child's zBMI below the threshold for obesity; appendix pp 9–10). A time factor in these simulations with cross-sectional data was not incorporated, but the stepped model inherently assumes that each step provides sufficient time to achieve the mean effect—follow-ups were typically 6–12 months after the end of the intervention.

We modelled data with the assumption that the baseline scenario, which was based on data between 2010 and 2019, involved no delivery of preventive or treatment interventions (ie, HSE participants might have received healthy lifestyle or weight-management interventions independent of the survey). Intervention scenarios made allowances for incomplete uptake but assumed high compliance and delivery against NICE guidance. These allowances and assumptions probably exceeded the current capacity for delivery; data from 2020 and 2021 suggest that only 23% of National Health Service (NHS) medical trusts deliver weight-management services for children and young people.[9]

The main outcomes of this modelling study were the estimated prevalence of clinical obesity defined as a BMI equal to or above the 98th centile on the UK90 growth chart[25] as a result of each scenario, and the difference in prevalence in comparison with the baseline estimate.

Statistical analysis

We used multiple imputation by chained equations to generate 100 datasets of the starting population. We generated these datasets to handle missing data, which were assumed to be missing at random, and to establish effect estimates, which were applied with variation from many sample populations. The analytical sample included all children and young people with data on age, zBMI, IMD quintiles (ie, a multidomain measure of relative deprivation for small areas of England ranked from people who were living in the 20% least deprived areas to people who were living in the 20% most deprived areas), ethnicity, and the weighting variable. Data were

	Eligibility criteria	Effect size	Uptake	Completion	Number of eligible people	Number of people who were treated
Tier 1: Universal, multicomponent interventions						
Age 2–4 years	Everyone	zBMI −0·07 (0·03)	100%	76·5%	4447	3402
Age 5–18 years	Everyone	zBMI −0·07 (0·04)	100%	100%	19 742	19 742
Tier 1: Brief-advice interventions						
Age 2–18 years	People with obesity	zBMI −0·04 (0·02)	51·2%	72·6%	2520	937
Tier 2: Lifestyle interventions						
Age 2–5 years	People with obesity	zBMI −0·38 (0·10)	57·3%	79·0%	297	134
Age 6–11 years	People with obesity	zBMI −0·06 (0·02)	NR	74·4%	1079	406
Age 12–18 years	People with obesity	zBMI −0·13 (0·04)	50·6%	79·0%	1144	457
Tier 3: Drug interventions						
Age 13–18 years (orlistat)	People with obesity with comorbidity	−0·79 kg/m² (0·15)	61·6%	63·6%	615	241
Age 13–18 years (liraglutide)	People with obesity with comorbidity	zBMI −0·22 (0·07)	61·6%	63·6%	615	241
Tier 4: Surgical interventions						
Age 13–18 years (gastric band)	People with class 2 obesity with comorbidity and people with class 3 obesity	−10·34 kg/m²* (1·71)	80·9%	100%	117	95
Age 13–18 years (sleeve gastrectomy)	People with class 2 obesity with comorbidity and people with class 3 obesity	−13·00 kg/m²* (1·02)	80·9%	100%	117	95
Age 13–18 years (gastric bypass)	People with class 2 obesity with comorbidity and people with class 3 obesity	−15·00 kg/m²* (0·77)	80·9%	100%	117	95

Data are effect size (SE), %, or n. NR=not reported. zBMI=BMI Z score. *Combined in proportion to the use of these interventions in England; equates to an overall effect size of −12·06 kg/m² (SE 0·34).

Table 1: **Overview of modelling scenarios**

also imputed for having an asthma diagnosis or mobility problems and household income (appendix p 8).

We estimated obesity prevalence from imputed data with 95% CIs by age, sex, ethnicity, government region, and deprivation (IMD quintiles from 2007 and 2015; table 1). Children and young people eligible for preventive and weight-management interventions were identified via zBMI in addition to variables indicating comorbidities (appendix p 2). The effects of these interventions were simulated by adjusting zBMI with the random number function in Stata,[28] with point estimates for mean effect size with SDs. If effects were provided with kg/m², interventions were simulated for eligible children via BMI, then BMI after the intervention was converted to zBMI. The random number function assumed a normal distribution around the mean, so effects were applied with random variation across the population. Uptake and completion rates were calculated based on the total number of eligible children and young people; simulated interventions were applied randomly among those who were eligible.

After simulated interventions, population prevalence was re-estimated and compared with baseline zBMI by age and deprivation. Absolute and relative change compared with baseline were assessed. Relative change is the percentage decrease relative to baseline, but in these analyses can also be expressed as the number of children in every 100 who changed to be below the 98th centile threshold of obesity. Changes in mean zBMI were also calculated for each intervention; change in prevalence of extreme obesity was also calculated after surgical intervention.

For the scenario representing staged care, treatment effects were simultaneously applied to exclusive groups (ie, children and young people only received the most intensive intervention for which they were eligible); uptake and completion rates were applied for each intervention. For sequential models representing stepped care, zBMI was refitted at each step, with eligibility and completion rates recalculated. Children that remained above the 98th centile threshold of obesity after each step received multiple interventions.

Two sensitivity analyses were done. First, if the uptake of interventions varied by socioeconomic status, we assumed that children and young people of families with low income (ie, less than 60% the UK median)[29] took up tier 2 interventions 20% less than families with middle income or high income. Although there is robust evidence regarding barriers and reduced engagement with services by disadvantaged communities, there is little evidence to quantify this disparity (appendix p 7). Second, if uptake and completion rates were both reduced by a third (ie, 33·3%) from what was achieved in RCTs, the scale-up of RCTs would be unlikely to achieve similar rates as trials. We continued to assume school-based preventive interventions were received by all children aged 5–18 years. We assumed that effect sizes were reliable but assumed twice the variance in this analysis, as effects would vary to a greater degree across a broader population. All analyses were done in Stata version 15.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, writing of the report, or the decision to submit the Article for publication, but did have the opportunity to review the Article before submission.

Results

There were 18 080 children and young people in the analytical sample. Clinical obesity prevalence was estimated to be 11·2% (95% CI 10·5–11·8) via weighted imputed data for all children and young people aged 2–18 years, and was found to develop strongly in early childhood. The prevalence of obesity was estimated at 5·0% for children aged 2–5 years and at more than double for children aged 6–9 years (10·3%). Clinical obesity (eligible for tiers 1 and 2), obesity with a comorbidity (eligible for tier 3), and severe obesity (eligible for tier 4) were estimated to be more prevalent among male children and young people, older children and young people, people who were more deprived, and the northeast and west regions (appendix p 5). Clinical obesity was estimated to vary by ethnic group (White 10·4%, Asian 12·1%, Black 14·7%, people from a mixed ethnic background 15·1%, and other 18·4%).

In modelling scenarios, universal, preventive interventions were estimated to lead to an overall decrease in the prevalence of obesity of 0·9% (95% CI 0·1 to 1·8), primary-care interventions were estimated to lead to an overall decrease of 0·2% (0·1 to 0·4), community and lifestyle interventions were estimated to lead to an overall decrease of 1·0% (0·1 to 2·1), pharmaceutical interventions were estimated to lead to an overall decrease of 0·2% (0·0 to 0·4), and surgical interventions were estimated to lead to an overall decrease of 0·4% (0·1 to 0·7). Relative change for a single tier of treatment was estimated to be greatest for community and lifestyle interventions followed by preventive interventions (table 2). Although surgical interventions had a relatively small effect, the prevalence of severe obesity was estimated to reduce from 0·6% to 0·4%, an absolute reduction of 0·2% (95% CI 0·0 to 0·4) and a relative change of 36·1% (appendix p 5). Staged care was estimated to result in an absolute decrease in the prevalence of obesity of 1·3% (–0·3 to 2·4), a relative change of 11·6%, and stepped care was estimated to lead to an absolute decrease of 2·4% (0·1 to 4·8), a relative change of 21·4% (figure 1). In terms of effects on zBMI (appendix p 7), a stepped-care approach was estimated to reduce mean zBMI by 0·09 (95% CI 0·00 to –0·16); staged care was estimated to reduce it by 0·07 (0·00 to –0·13), and preventive interventions was estimated to reduce it by 0·07 (0·00 to –0·14). Interventions from other management tiers was estimated to have a small effect on mean zBMI of –0·01 (0·00 to –0·02).

Results by age (table 2) showed that, of the single-tier interventions, preventive interventions was estimated to lead to the greatest reductions in the prevalence of obesity for children and young people aged 10–13 years. In community and lifestyle interventions specifically, absolute reductions in prevalence of obesity were estimated to be greatest in young people aged 17–18 years and relative reductions were estimated to be greatest in children aged 2–5 years. For tiers 3 and 4, children and young people aged 12 years or younger were not eligible. With liraglutide, the greatest reductions in the prevalence of obesity were estimated to be for children and young people aged 14–16 years, whereas in surgical interventions, the greatest reductions were estimated to be in young people aged 17–18 years. By exact age (appendix p 7) in pharmaceutical interventions, the biggest decreases in prevalence were estimated to be among children and young people aged 14 years and 15 years, with the biggest relative change observed among children and young people aged 15 years. By exact age in surgical interventions, the greatest absolute and relative decreases in prevalence were estimated to be for young people aged 18 years. Stepped and staged approaches were estimated to be most effective for children aged 14–16 years (table 2).

When assuming equal uptake across socioeconomic status, inequalities (ie, the prevalence of obesity among people who were the most deprived *vs* among people who were the least deprived) were estimated to reduce across all approaches. Results by deprivation showed that, of the single-tier interventions, preventive interventions and community and lifestyle interventions were estimated to lead to the greatest absolute reduction in inequalities in obesity, although the relative reduction was similar across all modelled scenarios or interventions (figure 2). The effect of preventive interventions was estimated to be relatively similar across IMD quintiles, but other interventions generally had greater effects in increasingly deprived quintiles (appendix p 6). Stepped care and staged care were estimated to lead to greater reductions in inequalities than any intervention in isolation. Stepped care was estimated to reduce the difference in prevalence of obesity between people who were the most deprived and people who were the least deprived from 8·0% to 6·4%.

In the first sensitivity analysis, in which families with low income took up community and lifestyle interventions 20% less than families with middle income or high income, inequalities in obesity were estimated to marginally increase, despite reductions in prevalence across all IMD quintiles (figure 2; appendix p 7). In the

	Prevalence of obesity	Absolute change	Relative change
Baseline			
Age 2–5 years	5·0% (4·1 to 5·9)	..	..
Age 6–9 years	10·3% (9·3 to 11·3)	..	..
Age 10–13 years	13·3% (11·7 to 14·8)	..	..
Age 14–16 years	12·5% (10·9 to 14·1)	..	..
Age 17–18 years	15·2% (13·2 to 17·3)	..	..
Overall	11·2% (10·5 to 11·8)	..	..
Tier 1: Preventive interventions			
Age 2–5 years	4·7% (3·9 to 5·6)	–0·3% (–0·1 to –0·6)	–6·0%
Age 6–9 years	9·5% (8·5 to 10·5)	–0·8% (0·0 to –1·6)	–7·8%
Age 10–13 years	12·0% (10·5 to 13·5)	–1·3% (–0·1 to –2·6)	–9·8%
Age 14–16 years	11·4% (9·8 to 12·9)	–1·1% (0·0 to –2·3)	–8·8%
Age 17–18 years	14·4% (12·4 to 16·4)	–0·8% (0·0 to –1·7)	–5·3%
Overall	10·3% (9·7 to 10·9)	–0·9% (–0·1 to –1·8)	–8·0%
Tier 1: Primary-care interventions			
Age 2–5 years	4·9% (4·1 to 5·8)	–0·1% (–0·1 to –0·2)	–2·0%
Age 6–9 years	10·1% (9·1 to 11·1)	–0·2% (0·0 to –0·4)	–1·9%
Age 10–13 years	13·0% (11·5 to 14·5)	–0·3% (–0·1 to –0·6)	–2·3%
Age 14–16 years	12·4% (10·8 to 13·9)	–0·1% (0·0 to –0·3)	–0·8%
Age 17–18 years	15·1% (13·0 to 17·1)	–0·1% (0·1 to –0·3)	–0·7%
Overall	11·0% (10·4 to 11·6)	–0·2% (–0·1 to –0·4)	–1·8%
Tier 2: Community and lifestyle interventions			
Age 2–5 years	4·3% (3·5 to 5·1)	–0·7% (–0·1 to –1·5)	–14·0%
Age 6–9 years	10·0% (9·0 to 11·0)	–0·3% (0·0 to –0·6)	–2·9%
Age 10–13 years	12·1% (10·6 to 13·6)	–1·2% (–0·1 to –2·4)	–9·0%
Age 14–16 years	11·3% (9·8 to 12·9)	–1·2% (–0·1 to –2·4)	–9·6%
Age 17–18 years	13·7% (11·7 to 15·6)	–1·5% (0·0 to –3·2)	–9·9%
Overall	10·2% (9·6 to 10·7)	–1·0% (–0·1 to –2·1)	–8·9%
Tier 3: Liraglutide			
Age 2–5 years	5·0% (4·1 to 5·9)	NA	NA
Age 6–9 years	10·3% (9·3 to 11·3)	NA	NA
Age 10–13 years	13·1% (11·6 to 14·6)	–0·2% (–0·1 to –0·4)	–1·5%
Age 14–16 years	12·0% (10·4 to 13·5)	–0·5% (0·0 to –1·1)	–4·0%
Age 17–18 years	14·8% (12·8 to 16·9)	–0·4% (0·0 to –0·8)	–2·6%
Overall	11·0% (10·3 to 11·6)	–0·2% (0·0 to –0·4)	–1·8%
Tier 4: Surgical interventions			
Age 2–5 years	5·0% (4·1 to 5·9)	NA	NA
Age 6–9 years	10·3% (9·3 to 11·3)	NA	NA
Age 10–13 years	13·2% (11·7 to 14·7)	–0·1% (–0·1 to –0·2)	–0·8%
Age 14–16 years	11·9% (10·4 to 13·5)	–0·6% (–0·1 to –1·2)	–4·8%
Age 17–18 years	14·2% (12·2 to 16·2)	–1·0% (0 to –2·1)	–6·6%
Overall	10·8% (10·2 to 11·5)	–0·4% (–0·1 to –0·7)	–3·6%
Staged care			
Age 2–5 years	4·3% (3·5 to 5·1)	–0·7% (–0·1 to –1·5)	–14·0%
Age 6–9 years	9·9% (8·9 to 10·9)	–0·4% (0·0 to –0·8)	–3·9%
Age 10–13 years	12·0% (10·6 to 13·5)	–1·3% (–0·2 to –2·6)	–9·8%
Age 14–16 years	10·6% (9·1 to 12·1)	–1·9% (–0·4 to –3·9)	–15·2%
Age 17–18 years	13·0% (11·0 to 14·9)	–2·2% (0·0 to –4·6)	–14·5%
Overall	9·9% (8·9 to 10·7)	–1·3% (0·3 to –2·4)	–11·6%
Stepped care			
Age 2–5 years	4·0% (3·2 to 4·7)	–1·0% (–0·1 to –2·2)	–20·0%
Age 6–9 years	9·1% (8·1 to 10·1)	–1·2% (0·0 to –2·4)	–11·7%
Age 10–13 years	10·5% (9·1 to 11·9)	–2·8% (–0·2 to –5·7)	–21·1%
Age 14–16 years	8·9% (7·5 to 10·3)	–3·6% (–0·2 to –7·4)	–28·8%
Age 17–18 years	11·6% (9·7 to 13·4)	–3·6% (–0·1 to –7·5)	–23·7%
Overall	8·8% (8·2 to 9·4)	–2·4% (–0·1 to –4·8)	–21·4%

(Table 2 continues in next column)

(Continued from previous column)

Data are % or % (95% CI). NA=not available.

Table 2: **Prevalence of obesity by age**

second sensitivity analysis (appendix p 8), in which uptake and completion were reduced by a third, reductions in prevalence were estimated to be similar compared with the original model for tier-1 prevention, tier-1 primary care, and tier-3 pharmaceutical interventions. Smaller reductions were observed compared with the original model for tier-2 lifestyle interventions and tier-4 surgical interventions. The greatest changes compared with original models were observed for systematic approaches, in which the prevalence of obesity was estimated to reduce by 0·8% (95% CI 0·1 to 1·6) for staged care and 2·0% (0·1 to 4·0) for stepped care in the second sensitivity analysis, compared with 1·3% (–0·3 to 2·4) and 2·4% (0·1 to 4·8) in the original model.

Discussion

We found that preventive and weight-management interventions could contribute to reducing childhood obesity in childhood and young adulthood if delivered systematically (eg, thorough methodical referral and use of services) and at scale (ie, across a broad population). The approach with the greatest potential effect was stepped care, in which each management tier was applied sequentially from the least to most intensive, resulting in a 2·4% reduction in obesity prevalence, equivalent to a 21·4% relative reduction in obesity. This reduction equates to approximately 275 000 children and young adults in England going from obese to non-obese. Of the individual interventions, universal, preventive interventions and community and lifestyle interventions had the biggest potential effect, reducing obesity prevalence by 0·9% (95% CI 0·1 to 1·8) and 1·0% (0·1 to 2·1), equivalent to an 8·0% relative reduction (ie, 108 000 fewer children with obesity) and an 8·9% relative reduction (ie, 115 000 fewer children with obesity). Our data suggested that if interventions are delivered systematically, and if equal uptake can be achieved across the socioeconomic spectrum, interventions are likely to contribute to narrowing the absolute gap in obesity prevalence between people who are the most deprived and people who are the least deprived. However, if uptake was 20% lower among

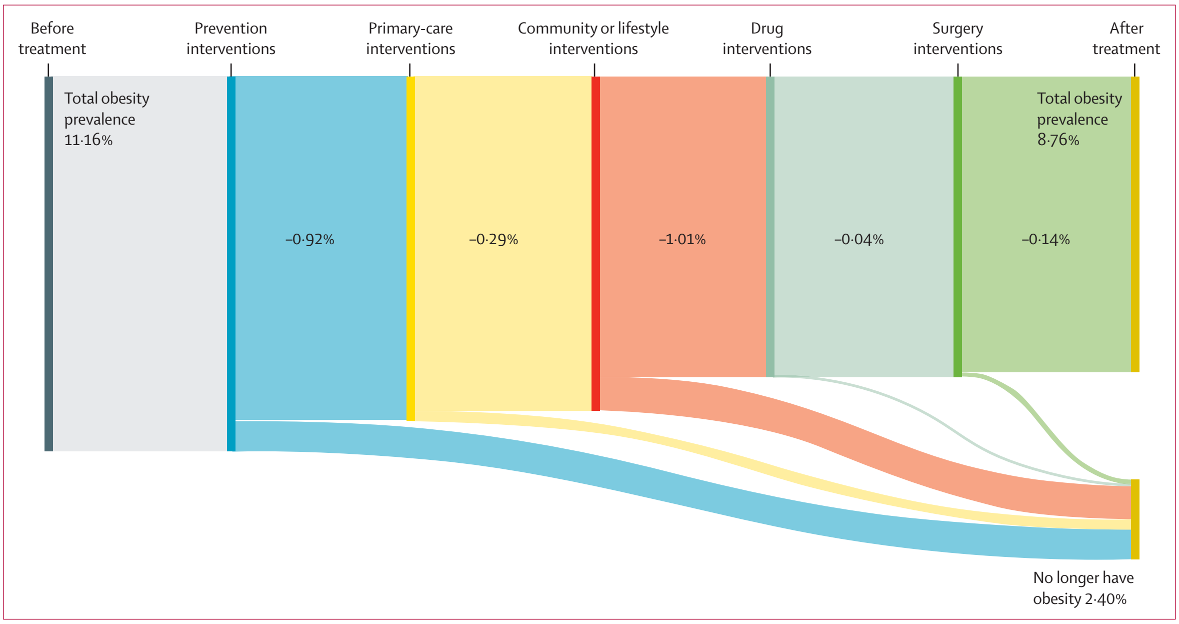

Figure 1: **Sankey diagram of the prevalence of obesity across interventions via a stepped-care approach**

people from more deprived groups, then such an approach might increase inequalities in obesity. Investment in scaled-up weight-management interventions has the potential to reduce the prevalence and inequalities in childhood obesity and obesity in young adulthood, but addressing the problem will also depend on effective policies that target the systematic and structural drivers of obesity.

We used nationally representative, population-based data for England, estimates of intervention effects from systematic reviews, and real-world data on uptake to model the potential effects of preventive and weight-management interventions delivered both systematically and at scale to children and young people in England. Compared with general-population data, our analytical sample included a higher proportion of children and young people living in deprivation and from minoritised ethnic groups including Asian, Black, and other non-White groups. We used published pooled effect sizes, but applied these with normal variation to represent the likelihood that interventions do not have equal effects for all children, with observations drawn from 100 datasets to minimise error.

Our findings have several limitations. Our approach did not use a recognised simulation or epidemiological modelling tool; rather, we simulated interventions by adjusting zBMI according to mean effect sizes and SDs derived from the highest standard of available evidence. Established modelling tools, such as the Preventable Risk Integrated Model,[30] tend to be focused on adults rather than children and associate risk factors, such as diet and physical activity, with health outcomes either directly or as mediated by BMI, and so were not suitable for our purposes.

We made the key assumption that health services had sufficient capacity for every child and young person in England to receive interventions for which they were eligible. Currently, in England, this assumption is not realistic because of the number of children and young people who are eligible for treatment and funding limitations on the NHS and Local Authorities in England. Although this assumption is not realistic, the objective of our work was to show the potential of weight-management interventions, not to recreate the obesity-treatment situation in England.

Our analyses combined cross-sectional data and did not consider changing trends in the prevalence of obesity in England between 2010 and 2019. Obesity prevalence did show some variation across these years, but changes were small (with the exception of 2019). These limitations were accepted to benefit from combining 10 years of data. We also assumed that population of children and young people at baseline had not received preventive or weight-management interventions. However, children and young people who had been effectively intervened upon—so that they no longer had obesity—would have been ineligible for the weight-management interventions modelled in this Article. Granular age was not available for the years 2016–19, meaning a mid-category age was assumed. Although not ideal, our findings were reported for age groups that aligned with age categories across these years. Our work also only considered the short-term outcomes of interventions (most evidence related to <12 months' follow-up), and these effects might not be maintained in the long term.[31]

Effects sizes that were applied in models were pooled estimates from meta-analyses of heterogeneous trials, with differences in intervention components and trial design. Although most evidence was from high-income countries, there might also have been differences in study and intervention contexts. Despite these limitations, pooled estimates are likely to provide better accuracy of effects than any one trial in isolation. Universal, preventive interventions for children aged 5–18 years assumed that all these children attended school and were compliant with the intervention. Although not all children attend school, the unauthorised attendance rate in 2018–19 in England was only 1·4%.[32] We also note the potentially promising effects of semaglutide,[33] but did not model its effects as it was not available via the NHS at the time of writing. We did not model interventions separately for male and female children and young people as sex-specific estimates were not provided for most interventions. For bariatric surgery, for which evidence suggested more than two-thirds of patients were female,[34] there was no sufficient number of eligible children and young people in the HSE sample to reflect this difference. Finally, we were not able to investigate the effects of interventions by comorbid conditions due to low numbers of children and young people with some recorded comorbid conditions.

Findings from our analyses were reported for the 98th BMI centile definition of obesity to be consistent with NICE. However, the use of this threshold underestimates the effects of higher-tier interventions on severe obesity prevalence. The use of thresholds for weight categories also simplifies the complex patterns of weight gain through adolescence. For example, relative larger effect sizes were observed among young teenagers for preventive or primary-care interventions, but these effects might be indicative of a higher proportion of children and young people who are marginally obese in this age group than in older teenagers. Conversely, younger age groups might have higher proportions of children and young people who were almost obese and therefore not eligible for treatment than older age groups. These issues represent a choice between shifting the BMI bell curve for a greater number of children and young people or truncating the BMI bell curve by targeting those at greatest risk. In this study, in which outcomes were measured by a clinical threshold of obesity, truncating the BMI bell curve was more effective.

Applying trial effects to populations is complex, as study samples often differ from the general population. Evidence suggests that preventive and treatment interventions for obesity have lower effects when scaled up from trials to broader populations,[35] but that there are implementation strategies that could improve the scale-up of interventions.[36] Furthermore, eligibility for trials might not have matched the NICE guidance, which was applied in this study. The strength of the evidence varied between interventions and tiers, with sparse data for some age groups and for higher tiers.

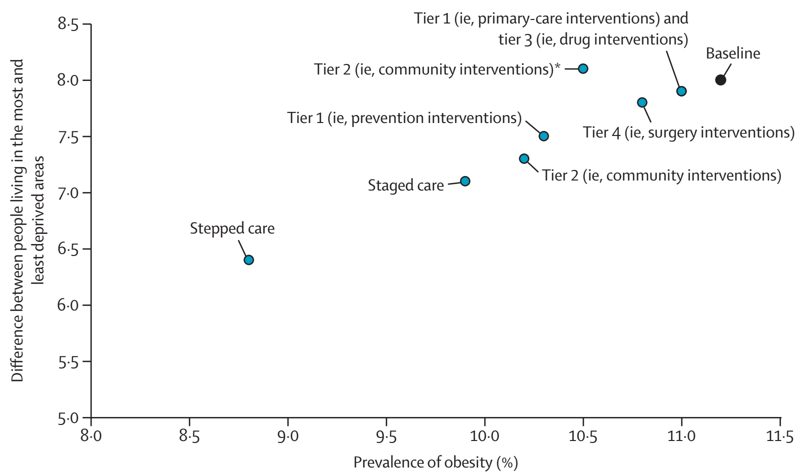

Figure 2: **Estimated prevalence of obesity plotted against level of deprivation**
*20% lower uptake among people with low income than among people with middle or high income.

Although our findings are based on a capacity of service that is not yet realistic, they are encouraging when compared with population-wide interventions. The soft-drinks industry levy, for example, was a tax implemented by the UK Government in 2018 on sugar-sweetened beverages to encourage the reformulation of products and reduce consumption of added sugar.[37] Interrupted time-series analysis, which estimated changes in the prevalence of childhood obesity compared with a counterfactual trend, suggested that the soft-drinks industry levy led to an absolute decrease in obesity prevalence (defined with the 95th centile) among children aged 10–11 years of 0·8%. However, the overall effect was disproportionate among female children (–1·6%) and male children (–0·2%).[38] Our findings suggest that scaled-up delivery of universal, preventive interventions or multicomponent lifestyle interventions for children with obesity would have similar effects, but at the clinical threshold of obesity (ie, the 98th centile).

Inequalities in childhood obesity are increasing,[3] and evidence suggests that people who are disadvantaged and diverse communities might be less likely to engage with health-care services and more likely to experience barriers when accessing treatment than people who are not disadvantaged or from minoritised groups.[39] Our analyses were not able to reflect differential uptake into services as data were not available to inform the extent of the disparity. However, sensitivity analysis considering differences in uptake showed that, despite reductions in the prevalence of obesity, inequalities in obesity increased. This increase is concerning as a higher proportion of children and young people from deprived areas compared with children and young people who were less deprived would have been eligible for treatment, as evidenced by greater absolute reductions in the prevalence of obesity among children and young people who were deprived when uptake was equal. Weight-management interventions will need to engage with people who are disadvantaged and diverse communities in an evidence-based, culturally sensitive way to identify and overcome barriers. Mechanisms that increase uptake, retention, and completion for people who are disadvantaged will need to be developed to ensure that treatment is equally effective across all sociodemographic strata.

To our knowledge, this study is the first modelling study to estimate the population effects of scaled-up preventive and treatment interventions for childhood obesity at a national level. Despite small effects at the individual level, if weight-management interventions were delivered at scale, particularly in a stepped-care approach, they could make a valuable contribution to reducing the overall prevalence of childhood obesity. Our findings show that childhood weight-management services can contribute to population health obesity targets, in addition to the clinical contribution that weight-management services make for individual children and young people. We emphasise that weight-management services alone are not sufficient to combat childhood obesity. Even the substantial reductions that were identified here with a well developed, high-capacity, stepped-care system, the system itself would not, alone, be able to reduce the increases that have been observed in childhood obesity in England since the 1990s. Childhood weight-management services should be considered as part of a broader population response that is based around preventive measures.

Future research should consider the cost-effectiveness of different preventive and treatment interventions in isolation and in combination. Because of the number of children who are eligible for tier-2 interventions and the available resources for service provision in England, future work should also consider incorporating digital weight-management programmes,[40] which might be easier to scale and quality assure and cheaper to deliver than traditional face-to-face programmes. Because of the number of children who are eligible for tier-2, weight-management interventions and the resources involved, digital programmes might be the only feasible way to achieve the desired scale. More work is needed to understand the differences in uptake, competition, and efficacy among different sociodemographic groups that will influence the effects on health inequalities and on overall effectiveness. National audit might be a useful first stage of achieving this aim, alongside other work to establish the effectiveness and best means to scale existing and novel interventions.[41]

Contributors

SJR and RMV conceptualised and designed the study. SJR conducted the analyses. All authors had full access to all the data in the study, contributed to the interpretation of results and writing of the Article, and had final responsibility for the decision to submit for publication. RMV and SJR directly accessed and verified underlying data.

Declaration of interests

We declare no competing interests.

Data sharing

All datasets that were analysed have been cited in this Article. The Health Survey for England is commissioned by NHS Digital, published by University College London and NatCen Social Research, and is available to higher-education institutions for non-commercial purposes via the UK Data Service. Disaggregated data for age were requested for the 2015 Survey; these data are available via special licence access from the UK Data Service.

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