Estimating Overweight Risk in Childhood From Predictors During Infancy

Q:1, 2, 3

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KEY WORDS
overweight, obesity, children, risk algorithm, infants, early-life

ABBREVIATIONS
95% CI—95% confidence interval
AUROC—area under the receiver operating curve
HCP—health care professional
IOTF—International Obesity Task Force
MCS—Millennium Cohort Study
NPV—negative predictive value
OR—odds ratio
PPV—positive predictive value

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WHAT'S KNOWN ON THIS SUBJECT: Several risk factors for both overweight and obesity in childhood are identifiable during infancy. Q:6

WHAT THIS STUDY ADDS: A simple risk algorithm can be used to quantify risk of overweight in children. It can be used to help identify at-risk infants in a clinical setting to facilitate targeted intervention.

abstract

OBJECTIVE: The aim of this study was to develop and validate a risk score algorithm for childhood overweight based on a prediction model in infants. Q:4, 5

METHODS: Analysis was conducted by using the UK Millennium Cohort Study. The cohort was divided randomly by using 80% of the sample for derivation of the risk algorithm and 20% of the sample for validation. Stepwise logistic regression determined a prediction model for childhood overweight at 3 years defined by the International Obesity Task Force criteria. Predictive metrics R^2, area under the receiver operating curve (AUROC), sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated.

RESULTS: Seven predictors were found to be significantly associated with overweight at 3 years in a mutually adjusted predictor model: gender, birth weight, weight gain, maternal prepregnancy BMI, paternal BMI, maternal smoking in pregnancy, and breastfeeding status. Risk scores ranged from 0 to 59 corresponding to a predicted risk from 4.1% to 73.8%. The model revealed moderately good predictive ability in both the derivation cohort (R^2 = 0.92, AUROC = 0.721, sensitivity = 0.699, specificity = 0.679, PPV = 38%, NPV = 87%) and validation cohort (R^2 = 0.84, AUROC = 0.755, sensitivity = 0.769, specificity = 0.665, PPV = 37%, NPV = 89%).

CONCLUSIONS: Using a prediction algorithm to identify at-risk infants could reduce levels of child overweight and obesity by enabling health professionals to target prevention more effectively. Further research needs to evaluate the clinical validity, feasibility, and acceptability of communicating this risk. *Pediatrics* 2013;132:1–8

In the United Kingdom in 2010, ~3 in 10 boys and girls (aged 2 to 15) were classed as either overweight or obese.[1] Rapid weight gain during infancy is associated with obesity between 6 and 8 years of age[2–4] and later life,[5–7] and although estimates vary, between 25%[8] and 33%[2] of infants gain weight rapidly during the first 6 months after birth. There is evidence that weight at 5 years of age is a good indicator of the future health of a child[9] and that obesity during childhood increases the risk of adult obesity. This has a clearly measurable impact on physical and mental health, quality of life, and generates considerable direct and indirect costs.[10] Thus, there is a compelling rationale for identifying those infants at greatest risk.

UK health policy suggests primary prevention and evidence-based interventions are important.[11,12] However, there is little guidance for health care professionals (HCPs) to support identification of infants at risk for developing childhood obesity. In the United Kingdom, health visitors and their team members deliver the Healthy Child Program[13] to parents of children younger than 5 years old. Studies have revealed that members of the health visiting team lacked guidance around identifying and intervening with infants who gain weight rapidly[14] and have low levels of knowledge about obesity risk.[15] The US Institute of Medicine has introduced early childhood obesity prevention guidance[16] suggesting that HCPs should undertake regular growth monitoring and consider obesity risk factors during infancy. A recent systematic review[17] has identified early-life risk factors of overweight in childhood thus offering the potential to develop a useful tool to identify infants at risk for obesity. Therefore, the aim of this study was to develop and validate a risk score algorithm for overweight in childhood based on predictors identified in the first year by using a large and contemporary British birth cohort.

METHODS

Participants

The Millennium Cohort Study (MCS) is a contemporary prospective birth cohort in the United Kingdom. Full details of the data collection and sampling design are provided elsewhere.[18] The study cohort analyzed data from 18 296 singleton infants aged 6 months to 12 months at the first interview. Preterm infants, multiple births, infants with congenital malformations, and specific medical conditions (diabetes, renal disease) were excluded from the analysis because these children have potentially different growth trajectories. The mean age of infants at the first interview was 9.2 months (SD 0.53). Children at follow-up (second interview) ranged from 31.9 months to 51.8 months of age with a mean age of 37.7 months (SD 2.5). The analysis was restricted to 13 513 singleton children who had complete anthropometric data at follow-up. The sample was divided into 2 cohorts: 80% of the sample was randomly selected to a derivation cohort for the development of the risk algorithm while the remaining 20% was used to validate the risk algorithm.

Outcome Measure

The primary clinical outcome for childhood overweight at 3 years was defined by the International Obesity Task Force (IOTF)[19] gender and age-specific cutoffs corresponding to an adult BMI $\geq$25 kg/m^2 (girls: $\geq$18.02 kg/m^2; boys: $\geq$18.41 kg/m^2). The outcome at 3 years was chosen as it was the mean age at follow-up where a diagnosis of overweight in early childhood could be made (there is no standard definition of overweight in children younger than 2 years of age).[19]

Risk Factors

Predictors in early-life were based on questions obtained from the first parent interview when infants were between 6 and 12 months. Predictors were selected based on a comprehensive systematic review[17] conducted by the research team on infant risk factors of overweight in childhood. Risk factors that were identified in Weng et al[17] as significantly associated with overweight in childhood were considered a priori. In total, 33 potential predictor variables were investigated across several categories (Supplemental Table 6). The majority of variables were presented in the MCS as categorical. However, several variables were dichotomized or categorized for logistic regression. Infant birth weight was categorized in quintiles, and rapid weight gain was defined as weight gain >0.67 SD change in weight-for-age *z* score in the infant's first year. This definition of rapid weight gain has been commonly used in other studies[6,20,21] and can be interpreted as crossing centile lines on a growth chart. Maternal prepregnancy BMI and paternal BMI were classified in categories: <18.5 kg/m^2; 18.5 to <25 kg/m^2; 25 to <30 kg/m^2; or $\geq$30 kg/m^2.

Statistical Analysis

Univariate logistic regression was used to test the significance between potential predictor variables and overweight in childhood. The likelihood test was used to consider the significance of individual predictor variables due to the categorical nature of the variables. Variables were considered statistically significant if likelihood *P* values were <5%. Predictor variables that were significant in the univariate analyses were included in a mutually adjusted model. Stepwise regression analysis, which can optimize the model by maximizing independence among predictors, was used to determine the best predictor model for overweight at 3 years.

Derivation and Validation of the Risk Algorithm

The risk prediction algorithm was developed and validated by using methods established in previous studies.[22–25] Using the mutually adjusted predictor model, we created an algorithm based on the relative strengths of β coefficients from logistic regression. A risk score was devised by assigning integer values to variable categories. All β coefficients in the adjusted model were divided by the β with the smallest value to obtain the relative strengths of each category. The value rounded to the nearest whole number was the assigned score. Reference categories were assigned an integer value of 0.

Once integer values were assigned to each of the variable categories, a total risk score was calculated for each individual within the derivation cohort. The total risk score was regressed against the overweight outcome by using logistic regression. The β coefficient from this regression analysis was used to derive the predicted risk of overweight by using the following function where *e* is the base of the natural logarithm, β is the regression coefficient, *X* is the total risk score, and *Y* is the regression constant:

$$\text{Predicted Probability of Risk} = e^{(\beta * X + Y)} / [e^{(\beta * X + Y)} + 1]$$

The risk score algorithm was applied to all individuals within the validation cohort. The predictive capability of the risk score was evaluated by plotting the total risk score against observed and expected risk for both the derivation and validation cohorts. Observed risk was calculated as the true proportion of those considered overweight at follow-up corresponding to each risk score. Model-fit was assessed by R^2 from the regression of observed risks against the predicted risk scores. Discrimination was evaluated by the area under the receiver operating curve (AUROC).[24] Additional predictive metrics of sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were provided.

RESULTS

Overall Study Population

At the 3-year follow-up from birth, 23.4% of all children in the derivation cohort were considered overweight. The mean BMI at follow-up was 16.85 kg/m^2. There were approximately equal representations of boys and girls in the entire sample. Deprived groups were overrepresented where 60% of children were from households that earned £20 800 ($33 292 USD) or less. Most children in the sample (83%) were from white ethnic backgrounds. Both the derivation and validation cohorts were similar in characteristics (Supplemental Table 7).

Predictor Variables

The unadjusted regression analysis identified associations between 16 potential predictors and childhood overweight (Table 1 and Supplemental Table 8). Seven predictors were included in a multivariate model (Table 2). Girls were 15% (95% confidence interval [CI]: 1.02–1.29, $P = .024$) more likely to be overweight than boys. Infants in the highest quintile of birth weight (≥3.81 kg) were 63% (95% CI: 1.33–1.98, $P < .001$) more likely to be overweight than infants in the lowest quintile (<2.93 kg) of birth weight. During the first year after birth, infants who experienced rapid weight gain were 4.15 (95% CI: 3.64–4.73, $P < .001$) times more likely to be overweight than infants who had not experienced rapid weight gain. Children of mothers who were overweight (odds ratio [OR] = 2.98 [95% CI: 1.60–3.47], $P < .001$) or obese (OR = 2.35 [95% CI: 1.60–3.47], $P = .001$) before pregnancy were more likely to be overweight than children of mothers who were underweight. Children of fathers (OR = 1.98 [95% CI: 1.00–3.96], $P = .053$) who were obese were more likely to be overweight than children of fathers who were underweight. Children of mothers who smoked during pregnancy were 33% (95% CI: 1.15–1.55, $P < .001$) more likely to be overweight than children of mothers who had not smoked. Infants

TABLE 1 Univariate Associations From Logistic Regression Between Predictor Variables During Infancy and Overweight Status at 3 Years

Potential Risk Factors	Likelihood *P*
Maternal marital status	<.05
Ethnicity	<.05
Number of own children	.67
Maternal education	.54
Maternal employment	<.05
Employment in pregnancy	.06
Household income	<.05
Financial status	.57
Child care arrangements	<.05
Child's gender[a]	.08
Birth weight[a]	<.05
Rapid weight gain[a]	<.05
Type of delivery	.14
Maternal age	.87
Maternal prepregnancy BMI[a]	<.05
Paternal BMI[a]	<.05
Maternal smoking in pregnancy[a]	<.05
Maternal alcohol consumption	<.05
Maternal feelings of depression	.37
Maternal health	.24
Maternal diabetes	<.05
Ever breastfed[a]	<.05
Breastfeeding duration	<.05
Ever formula fed	<.05
Introduction of solid food	.11
Unhappy feeding interrupted	.43
Makes a fuss going to sleep	.86
Makes a fuss after waking	.35
Upset when not getting things	.97
Infant can sit up	<.05
Infant can stand holding on	.40
Infant can grab objects	.30
Infant can hold objects	.94
Infant can walk	.85

Unadjusted OR and 95% CI are provided in Supplemental Table 8.
[a] A priori variable.

TABLE 2 Multivariate Logistic Regression of Mutually Adjusted Early-Life Risk Factors on Odds of Childhood Overweight at 3 Years Q:13

Risk Factors	Adjusted OR	95% CI	
		LCL	UCL
Gender			
Boy	Ref	—	—
Girl	1.15	1.02	1.29
Infant birth weight (quintiles)			
<2.93 kg	Ref	—	—
2.93 to <3.24 kg	1.08	0.87	1.33
3.24 to <3.49 kg	1.24	1.01	1.51
3.49 to <3.81 kg	1.44	1.18	1.75
≥3.81 kg	1.63	1.33	1.98
Infant rapid weight gain in first year			
No (≤0.67 SD ΔWFA *z* score)	Ref	—	—
Yes (>0.67 SD ΔWFA *z* score)	4.15	3.64	4.73
Maternal prepregnancy weight status			
<18.5 kg/m^2	Ref	—	—
18.5 to <25 kg/m^2	1.76	1.21	2.56
25 to <30 kg/m^2	2.35	1.60	3.47
≥30 kg/m^2	2.98	1.98	4.47
Paternal BMI			
<18.5 kg/m^2	Ref	—	—
18.5 to <25 kg/m^2	1.09	0.55	2.15
25 to <30 kg/m^2	1.57	0.79	3.10
≥30 kg/m^2	1.98	1.00	3.96
Maternal smoking in pregnancy			
No	Ref	—	—
Yes	1.33	1.15	1.55
Ever breastfed infant in first year			
No	1.25	1.09	1.42
Yes	Ref	—	—

who were never breastfed in the first year were 25% (95% CI: 1.09–1.42, P = .001) more likely to be overweight than children who were breastfed.

Risk Score Algorithm

The integer values of the risk algorithm are given in Table 3. According to integer values, the strongest risk factors were rapid weight gain, infant birth weight >3.81 kg, maternal prepregnancy BMI from 25 kg/m^2 to 30 kg/m^2, maternal prepregnancy BMI ≥30 kg/m^2, and paternal BMI ≥30 kg/m^2. Other risk factors were assigned relatively smaller integer values. The total risk score ranged from a minimum of 0 to a maximum of 59 (interquartile range: 17–35). In Table 4, the predicted probability of risk of overweight was constrained from 4.1% to 73.8%. The risk scores were separated into quintiles corresponding to observed frequencies of predicted risks providing pragmatic risk categories (Table 4).

Validation

Total risk scores were plotted against observed and predicted risks of overweight for both the derivation (Fig 1) and validation (Fig 2) cohorts. Observed risks trended well with predicted risks in both cohorts. When observed risk was regressed against the risk scores, high R^2 values were seem in both the derivation (R^2 = 0.92) and validation cohorts (R^2 = 0.84) suggesting a good model-fit. The AUROC for the derivation and validation cohort was 0.721 and 0.755, respectively (Table 5). This means there was a 72% to 76% probability that the predicted risk score was higher in children diagnosed as overweight than in children who were not overweight.

Additional metrics of sensitivity, specificity, PPV, and NPV were provided in Table 5, which evaluated how well the algorithm predicted high risk infants (defined as infants who obtained a risk score ≥25 corresponding to the top 2 quintiles of predicted risks in Table 4). The sensitivity of the risk algorithm for predicting high risk infants was 0.699 for the derivation cohort and 0.769 for the validation cohort, whereas the specificity was 0.676 for the derivation cohort and 0.665 for the validation cohort. Using the study prevalence of overweight, the PPV for overweight at 3 years was 38% for the derivation cohort and 37% for the validation cohort. The NPV was 87% for the derivation cohort and 89% for the validation cohort.

DISCUSSION

The growing prevalence of childhood Q:7 overweight has warranted exploration into risk prediction models to aid prevention strategies. Although a recent risk model[26] derived risk equations to predict childhood obesity at birth with good statistical validity (AUROC: 0.7–0.85), the risk algorithm described in this study identifies children between 6 and 12 months at risk for overweight. It, therefore, is able to incorporate the effects of rapid weight gain, which is the strongest marker of overweight and obesity in childhood.[6,7,27] Additionally, it may be more effective and acceptable to communicate overweight

TABLE 3 Integer Values for Predictor Variables of Childhood Overweight at 3 Years Q:14

Risk Factors	β Coefficient	Integer Score
Gender		
Boy	Ref	0
Girl	0.1366	2
Infant birth weight (quintiles)		
<2.93 kg	Ref	0
2.93 to <3.24 kg	0.0741	1
3.24 to <3.49 kg	0.2114	3
3.49 to <3.81 kg	0.3612	5
≥3.81 kg	0.4859	7
Infant rapid weight gain in first year		
No (≤0.67 SD ΔWFA *z* score)	Ref	0
Yes (>0.67 SD ΔWFA *z* score)	1.4239	19
Maternal prepregnancy weight status		
<18.5 kg/m^2	Ref	0
18.5 to <25 kg/m^2	0.5658	8
25 to <30 kg/m^2	0.8560	12
≥30 kg/m^2	1.0906	15
Paternal BMI		
<18.5 kg/m^2	Ref	0
18.5 to <25 kg/m^2	0.0824	1
25 to <30 kg/m^2	0.4495	6
≥30 kg/m^2	0.6832	9
Maternal smoking in pregnancy		
No	Ref	0
Yes	0.2884	4
Ever breastfed infant in first year		
No	0.2199	3
Yes	Ref	0

Proof Only

TABLE 4 Predicted Risks of Overweight at 3 Years Corresponding to Total Risk Scores

Quintile	Risk Scores	Risk of Overweight, %	Risk Category
1	0–15	4.1–11.1	Very low risk
2	16–19	11.8–14.2	Low risk
3	20–24	15.1–19.1	Medium risk
4	25–37	20.2–37.2	High risk
5	38–59	38.9–73.8	Very high risk

Risk scores for the validation cohort (*n* = 1715). Categories of risk given in quintiles corresponding to predicted risk cutoffs.

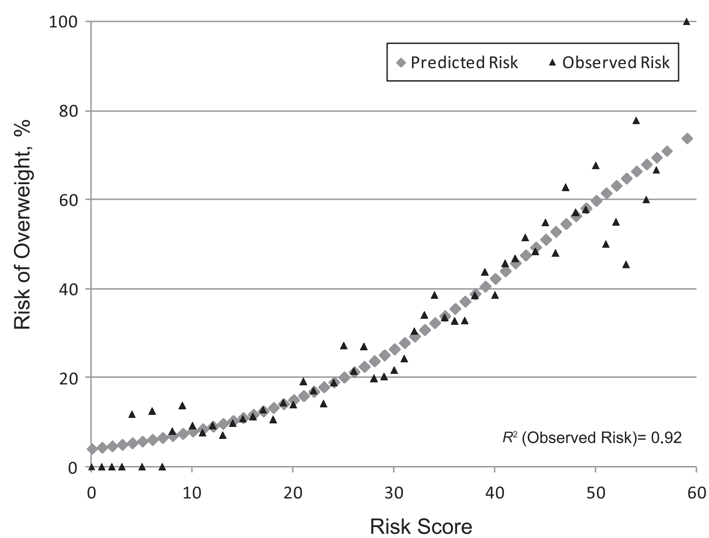

FIGURE 1
Observed and predicted risk of overweight at 3 years by total risk scores for the derivation cohort (*n* = 8299).

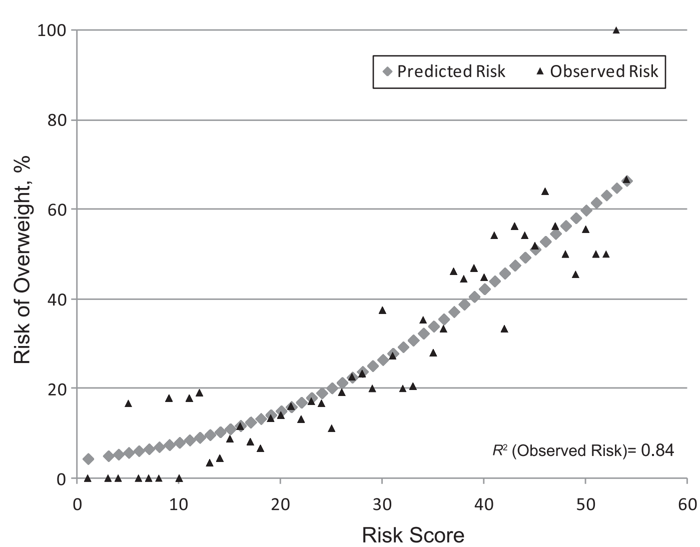

FIGURE 2
Observed and predicted risk of overweight at 3 years by total.

risk to parents of infants at 6 and 12 months when the rapid weight gain is manifested. A US study revealed that positive parental changes occurred when a physical marker is visible such as a diagnosis of childhood overweight or perceiving the child's weight as a health problem.[28] There are 2 other risk prediction models[27,29,30] with Q:8 moderately good levels of predictability (AUROC: 0.7–0.8), which both included weight gain during the first year to predict childhood overweight or obesity. However, a significant advantage of the current study is that the variables used in the model were based on a comprehensive systematic review[17] by the research team and were identified as being strongly associated with overweight risk in childhood.

The overweight outcome in this study was defined by IOTF criteria where the prevalence of overweight at 3 years was 23.4%. This is similar to the UK national estimate (>85th percentile based on UK growth charts) where 22.6%[1] of children aged 4 to 5 were overweight. Using IOTF criteria results in a higher PPV due to a more stringent definition (≈ > 90th percentile based on UK growth charts). Applying the algorithm in this study on the validation cohort of 1715 children would identify 686 infants who achieved a high risk score and would subsequently be given intervention. Assuming intervention was 100% effective, this would avert 253 cases (PPV = 37%) of childhood overweight while 433 children would be misclassified as high risk. For the 1029 children who did not achieve a high risk score, only 114 children would be misclassified as low risk and become overweight (NPV = 89%). This level of accuracy in the PPV may not be ideal but may nevertheless yield preventive benefits.

First, early identification should serve to enhance the effectiveness of obesity interventions by targeting "at risk" children from a young age.[31] The American Academy of Pediatrics has suggested that identification and referral for treatment during early childhood yields greater success in treatment.[31] Observational evidence has shown that younger age of the

TABLE 5 Diagnostic Measures for Assessing the Predictive Capability of the Risk Algorithm for Overweight at 3 Years in Both the Derivation and Validation Cohorts

Diagnostic Measure	Derivation Cohort	Validation Cohort
Sample size	8299	1715
Sensitivity[a]	0.699	0.769
Specificity[a]	0.676	0.665
AUROC	0.721	0.755
PPV[a,b]	38%	37%
NPV[a,b]	87%	89%

[a] Based on a risk score threshold ≥25 corresponding to high risk groups.

[b] Based on overweight prevalence of 23.4% in the derivation cohort and 22.7% in the validation cohort.

child during parental lifestyle interventions is significantly associated with better long-term outcomes compared with older children.[32] Second, both parents and HCPs underestimate obesity risk indicating that identification may be useful. Studies[33–36] have consistently revealed that the majority of parents were not aware of their child's obesity risk; however, this was not usually due to the inability of parents to identify the weight status of their children but rather their perception of what was considered healthy weight. Studies have also revealed that clinicians only diagnose overweight or obesity in 1.1% to 31% of all overweight children, leading to suboptimal levels advice given and referrals to appropriate interventions.[37–39] HCPs are wary of approaching clients about overweight and obesity, and they may be reluctant to identify risk because of the impact on the client-professional relationship.[15] Considering rates of overweight or obesity diagnoses are suboptimal in current practice, a risk assessment tool even with moderate sensitivity and specificity would identify children who would have otherwise been missed. The proposed model would accurately exclude a number of children who would not become overweight from targeted intervention due to its high NPV. This could potentially maximize resource allocation to prioritize infants at the greatest risk. However, the negative consequences of misidentification such as the adverse effects of potentially stigmatizing parents need to be evaluated. Third, the benefits of intervention may outweigh the risks of intervening unnecessarily. Although the risks of intervening unnecessarily need to be considered, this may actually be overstated. Recent studies[28,40] have revealed that counseling on weight status at an early age is significantly associated with encouraging positive parental lifestyle change. Additionally, the postnatal interventions that are recommended to reduce obesity risk should have very few deleterious effects as they focus on parental support, nutritional modification, healthy eating, and breastfeeding.[41–44] Finally, this study has revealed the importance of the prenatal and preconception environment. High prepregnancy BMI is linked to intrauterine exposures of early overnutrition and programming, which may have a lasting influence by determining body composition.[45,46] Contradictorily, maternal smoking in pregnancy is associated with in utero growth restriction but also increase later risk of childhood obesity.[17,47] It is suggested that infants of mothers who had smoked in pregnancy often exhibit high rapid postnatal weight gain.[48,49] Smoking in pregnancy may also be a proxy for other social and lifestyle characteristics including poor dietary choices and socioeconomic status.[50] It is important to investigate whether addressing these potentially modifiable risk factors such as maternal smoking in pregnancy and high infant birth weight can reduce the risk of obesity in children and reduce the burden of intervention in the postnatal period.

There were several limitations regarding the study design and sampling in the MCS. The sampling in the MCS represents more deprived communities and ethnic minorities. Nearly 60% of children were from families with incomes of £21 800 ($33 292 USD) or less, and 17% were from ethnic minority families. BMI is known to systematically underestimate or overestimate adiposity in certain ethnic groups because of its association with height.[51] Although BMI is highly correlated with direct measurements of adiposity, it is also influenced by lean body and bone mass. Another limitation of the study design was that maternal prepregnancy BMI was self-reported and therefore was subject to recall bias. There was no clinical validation of these measures or linkages to previous health records. Finally, infant growth was calculated by using a single cutoff to define rapid weight gain due to a single anthropometric assessment in the first year. Thus, the shape of the growth curves could not be taken into account.

There were also limitations of the analysis. Although the stepwise regression approach can minimize dependence of variables in the model, the indirect effects and path structure of the prediction variables was not determined. Prepregnancy weight is strongly associated with in utero overnutrition and high birth weight. Subsequently, both high birth weight and maternal prepregnancy BMI were also associated with childhood overweight. Although this does not detract from the predictive score, it is important to note that these factors are not independent. Further limitations include the unknown extent the model can predict longer term outcomes due to the study's relatively short follow-up length. Future research could examine the accuracy by using studies with longer follow-up durations.

CONCLUSIONS

A risk algorithm was based on several easily observable risk factors in the first year, which predicted childhood overweight. Using a prediction algorithm to identify at-risk infants could reduce levels of child obesity by enabling health professionals to target prevention more effectively. However, further research needs to evaluate the clinical validity, feasibility, and acceptability of communicating this risk.

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5—Please confirm whether funding for this research was provided by the National Institutes of Health. If so, please provide any relevant grant information if it has not already been noted.

6—Per journal style, text for "What's known on this subject" and "What this study adds" may not exceed 40 words each. Please amend as necessary to meet this requirement.

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13—In Table 2, please spell out LCL and UCL.

14—In Tables 2 and 3, and Supplemental Tables 6, 7, and 8, please spell out WFA.

Supplemental Information

SUPPLEMENTAL TABLE 6 Definitions of Potential Risk Factors of Overweight in Childhood

Variable	Type	Description
Demographic		
Maternal marital status	Categorical	Single; Widowed; Separated; Married
Ethnicity	Categorical	White; Asian; Black; Other
Number of own children	Categorical	One; Two; Three; Four or more
Maternal education	Categorical	None; Other; O level/GCSE; A/AS/S levels; Diploma; Degree
Maternal employment	Categorical	Never employed; Unemployed; Maternity leave; Employed
Employment in pregnancy	Binary	No; Yes
Household income (£)	Categorical	<£20 800 ($33 292 USD); £20 800–£41 600 ($33 292–$66 584 USD); >£41 600 ($66 584 USD)
Financial status	Categorical	Very difficult; Quite difficult; Getting by; Okay; Comfortable
Child care arrangements	Binary	No; Yes
Infant characteristics		
Child's gender	Categorical	Boy; Girl
Birth weight	Categorical	<2.93 kg; 2.93 to <3.24 kg; 3.24 to <3.49 kg; 3.49 to <3.81 kg; ≥3.81 kg
Rapid weight gain	Binary	No (≤0.67 SD change in WFA *z* score); Yes (>0.67 SD in WFA *z* score)
Delivery type	Categorical	Normal; Instrumental; Caesarean
Parental characteristics		
Maternal age	Categorical	<20; 20 to 29; 30 to 39; ≥40 y
Maternal prepregnancy BMI	Categorical	<18.5 kg/m^2; 18.5 to <25 kg/m^2; 25 to <30 kg/m^2; ≥30 kg/m^2
Paternal BMI	Categorical	<18.5 kg/m^2; 18.5 to <25 kg/m^2; 25 to <30 kg/m^2; ≥30 kg/m^2
Maternal smoking in pregnancy	Binary	No; Yes
Maternal alcohol consumption	Categorical	Never; Monthly; Weekly; Daily
Maternal feelings of depression	Categorical	No; Yes
Maternal health	Categorical	Poor; Fair; Good; Excellent
Maternal diabetes	Binary	No; Yes
Infant feeding		
Ever breastfed	Binary	No; Yes
Breastfeeding duration	Categorical	<1 mo; 1 to 2 mo; 3 to 4 mo; 5 to 6 mo; 7 to 8 mo; ≥9 mo
Ever formula fed	Binary	No; Yes
Introduction of solid food	Categorical	1 to 2 mo; 3 to 4 mo; 5 to 6 mo; 7 to 8 mo; 9 to 10 mo
Infant temperament		
Unhappy feeding interrupted	Categorical	Never; Rarely; Usually not; Often; Always; Not sure
Makes a fuss going to sleep	Categorical	Never; Rarely; Usually not; Often; Always; Not sure
Makes a fuss after waking	Categorical	Never; Rarely; Usually not; Often; Always; Not sure
Upset when not getting things	Categorical	Never; Rarely; Usually not; Often; Always; Not sure
Infant physical development		
Does the infant sit up?	Categorical	Not yet; Once or twice; Often
Does the infant stand?	Categorical	Not yet; Once or twice; Often
Does the infant grab objects?	Categorical	Not yet; Once or twice; Often
Does the infant hold objects?	Categorical	Not yet; Once or twice; Often
Can the infant walk?	Categorical	Not yet; Once or twice; Often

SUPPLEMENTAL TABLE 7 Baseline Characteristics by Derivation and Validation Cohorts

Potential Risk Factors	Derivation Cohort, Total *N* (% Overweight)	Validation Cohort, Total *N* (% Overweight)
Maternal marital status		
Single	3334 (25.2)	807 (23.7)
Widowed	18 (22.2)	6 (33.3)
Separated	720 (26.4)	190 (28.9)
Married	6766 (22.7)	1676 (21.8)
Ethnicity		
White	9174 (24.4)	2276 (23.3)
Asian	935 (16.2)	215 (18.1)
Black	305 (28.5)	79 (29.1)
Other	425 (22.2)	109 (18.4)
Number of own children		
1	10 477 (23.7)	2589 (22.9)
2	254 (23.2)	72 (16.7)
3	77 (22.0)	12 (41.7)
4 or more	30 (33.3)	6 (16.7)
Maternal education		
None	1809 (24.2)	419 (21.0)
Other	259 (22.0)	71 (15.5)
O Level/GCSE	4754 (24.3)	1221 (24.9)
A/AS/S Levels	1073 (23.2)	248 (14.9)
Diploma	999 (23.8)	258 (25.9)
Degree	1924 (22.2)	460 (22.8)
Maternal employment		
Never employed	931 (21.2)	222 (22.5)
Currently unemployed	4451 (22.9)	1087 (23.8)
On maternity leave	273 (20.9)	73 (16.4)
Current employed	5173 (24.9)	1294 (22.4)
Employment in pregnancy		
No	3752 (22.7)	888 (23.4)
Yes	7083 (24.3)	1790 (22.6)
Household income		
<£20 800 ($33 292 USD)	5717 (23.1)	1362 (23.6)
£20 800–£41 600 ($33 292–$66 584 USD)	3205 (24.9)	818 (21.8)
>£41 600 ($66 584 USD)	1093 (19.9)	287 (22.7)
Financial status		
Very difficult	263 (25.9)	74 (20.3)
Quite difficult	840 (25.7)	209 (22.9)
Just getting by	2976 (23.5)	684 (22.9)
Doing okay	4127 (23.7)	993 (23.8)
Comfortable	2620 (23.2)	718 (21.7)
Child care arrangements		
No	5421 (22.7)	1336 (24.0)
Yes	5388 (24.8)	1338 (21.8)
Child's gender		
Boy	5453 (22.9)	1354 (23.6)
Girl	5386 (24.4)	1325 (22.2)
Birth weight (quintiles)		
<2.93 kg	2251 (15.9)	567 (17.5)
2.93 to <3.24 kg	2077 (19.6)	544 (15.6)
3.24 to <3.49 kg	2114 (23.4)	495 (23.6)
3.49 to <3.81 kg	2244 (25.9)	550 (25.5)
≥3.81 kg	2149 (33.8)	552 (32.9)
Rapid weight gain		
No (≤0.67 SD ΔWFA *z* score)	7388 (15.2)	1862 (14.9)
Yes (>0.67 SD ΔWFA *z* score)	3268 (42.9)	772 (42.9)
Type of delivery		
Normal	7319 (23.2)	1840 (21.5)
Instrumental	2442 (25.1)	582 (26.5)
Caesarean	1078 (24.4)	257 (24.5)

SUPPLEMENTAL TABLE 7 Continued

Potential Risk Factors	Derivation Cohort, Total *N* (% Overweight)	Validation Cohort, Total *N* (% Overweight)
Maternal age		
<20 y	405 (23.9)	88 (26.1)
20 to 29 y	4333 (23.8)	1032 (24.2)
30 to 39 y	5622 (23.8)	1419 (21.4)
≥40 y	479 (22.1)	140 (26.4)
Maternal prepregnancy BMI		
<18.5 kg/m^2	559 (13.9)	121 (20.7)
18.5 to <25 kg/m^2	6758 (21.1)	1643 (19.4)
25 to <30 kg/m^2	2044 (29.6)	540 (27.6)
≥30 kg/m^2	974 (34.4)	228 (35.9)
Paternal BMI		
<18.5 kg/m^2	75 (16)	12 (16.7)
18.5 to <25 kg/m^2	2953 (18.8)	724 (17.3)
25 to <30 kg/m^2	3298 (25.4)	823 (24.8)
≥30 kg/m^2	1003 (30.9)	242 (32.2)
Maternal smoking in pregnancy		
No	8270 (22.9)	2066 (22.8)
Yes	2569 (26.8)	613 (26.1)
Maternal alcohol consumption		
Never	2352 (23.1)	569 (20.7)
Monthly	4353 (24.2)	1042 (25.5)
Weekly	3614 (24.1)	933 (20.8)
Daily	519 (19.1)	135 (25.9)
Maternal feelings of depression		
No	8201 (23.5)	2046 (22.7)
Yes	2537 (24.4)	632 (23.3)
Maternal health		
Poor	290 (26.9)	65 (13.9)
Fair	1531 (24.5)	392 (23.9)
Good	5705 (23.9)	1347 (22.4)
Excellent	3310 (22.7)	875 (23.9)
Maternal diabetes		
No	10 612 (23.6)	2633 (22.9)
Yes	227 (29.5)	46 (19.6)
Ever breastfed		
No	3251 (26.3)	872 (24.1)
Yes	7588 (22.6)	1807 (22.3)
Breastfeeding duration		
<1 mo	2281 (22.9)	616 (25.5)
1 to 2 mo	1515 (22.8)	353 (20.4)
3 to 4 mo	1027 (24.7)	243 (21.4)
5 to 6 mo	727 (24.4)	171 (16.9)
7 to 8 mo	1469 (20.1)	353 (22.9)
≥9 mo	269 (19.3)	71 (16.9)
Ever formula fed		
No	574 (17.9)	135 (20.0)
Yes	10 263 (24.0)	2544 (23.0)
Introduction of solid food		
1 to 2 mo	178 (32.0)	49 (36.7)
3 to 4 mo	7118 (23.4)	1707 (22.2)
5 to 6 mo	1373 (22.9)	348 (23.3)
7 to 8 mo	215 (23.7)	62 (24.2)
9 to 10 mo	23 (17.4)	5 (20.0)
Unhappy feeding interrupted		
Never	3181 (23.8)	816 (23.5)
Rarely	3638 (22.9)	860 (22.4)
Usually not	1710 (23.6)	427 (18.3)
Often	1265 (23.8)	316 (27.5)
Always	674 (26.9)	155 (27.1)
Not sure	370 (24.6)	105 (20.0)

SUPPLEMENTAL TABLE 7 Continued

Potential Risk Factors	Derivation Cohort, Total *N* (% Overweight)	Validation Cohort, Total *N* (% Overweight)
Makes a fuss going to sleep		
Never	1428 (23.0)	349 (20.3)
Rarely	2839 (23.7)	693 (24.7)
Usually not	2308 (23.1)	586 (21.7)
Often	2554 (24.6)	614 (24.3)
Always	1366 (23.9)	342 (22.5)
Not sure	341 (23.8)	95 (18.9)
Makes a fuss after waking		
Never	3480 (24.8)	825 (24.5)
Rarely	3065 (23.6)	755 (24.2)
Usually not	1931 (23.6)	481 (23.1)
Often	1407 (22.1)	364 (19.8)
Always	642 (21.9)	161 (17.4)
Not sure	320 (23.4)	93 (18.3)
Upset when not getting things		
Never	1062 (24.6)	265 (27.2)
Rarely	2979 (23.6)	719 (20.0)
Usually not	2376 (23.9)	589 (25.6)
Often	2975 (23.3)	742 (22.6)
Always	1016 (23.7)	251 (22.7)
Not sure	426 (23.0)	113 (18.6)
Infant can sit up		
Not yet	207 (15.9)	41 (17.1)
Once or twice	241 (20.8)	72 (22.2)
Often	10 390 (23.9)	2566 (22.9)
Infant can stand holding on		
Not yet	1970 (24.7)	462 (23.2)
Once or twice	1263 (24.3)	210 (25.8)
Often	7605 (23.3)	1907 (22.3)
Infant can grab objects		
Not yet	16 (31.3)	5 (20.0)
Once or twice	66 (16.7)	11 (27.3)
Often	10 757 (23.7)	2663 (22.9)
Infant can hold objects		
Not yet	414 (23.2)	107 (21.5)
Once or twice	721 (23.3)	168 (26.8)
Often	9669 (23.7)	2400 (22.7)
Infant can walk		
Not yet	414 (23.2)	2345 (23.2)
Once or twice	721 (23.3)	193 (17.6)
Often	9669 (23.7)	141 (24.8)

Sample size and percentage of children characterized as overweight in each subgroup.

SUPPLEMENTAL TABLE 8 Unadjusted ORs and 95% CIs for Univariate Associations Between Potential Predictor Variables and Overweight Outcome at 3 Years (Derivation Cohort)

Potential Risk Factors	Unadjusted OR	95% CI
Maternal marital status		
Single	Ref	—
Widowed	0.85	0.28–2.58
Separated	1.06	0.88–1.28
Married	0.87	0.79–0.96
Ethnicity		
White	Ref	—
Asian	0.60	0.50–0.72
Black	1.24	0.96–1.59
Other	0.89	0.71–1.13
Number of own children		
1	Ref	—
2	0.97	0.73–1.31
3	0.91	0.53–1.57
4 or more	1.61	0.75–3.44
Maternal education		
None	Ref	—
Other	0.88	0.65–1.21
O Level/GCSE	1.00	0.89–1.14
A/AS/S Levels	0.95	0.79–1.13
Diploma	0.98	0.82–1.17
Degree	0.90	0.77–1.04
Maternal employment		
Never employed	Ref	—
Currently unemployed	1.11	0.93–1.32
On maternity leave	0.98	0.71–1.37
Current employed	1.24	1.05–1.47
Employment in pregnancy		
No	Ref	—
Yes	1.09	1.00–1.20
Household income		
<£20 800 ($33 292 USD)	1.28	1.09–1.50
£20 800–£41 600 ($33 292–$66 584 USD)	1.34	1.13–1.59
>£41 600 ($66 584 USD)	Ref	—
Financial status		
Very difficult	Ref	—
Quite difficult	0.99	0.72–1.36
Just getting by	0.88	0.66–1.17
Doing okay	0.89	0.67–1.18
Comfortable	0.87	0.65–1.16
Child care arrangements		
No	Ref	—
Yes	1.13	1.03–1.23
Child's gender		
Boy	Ref	—
Girl	1.08	0.99–1.18
Birth weight (quintiles)		
<2.93 kg	Ref	—
2.93 to <3.24 kg	1.29	1.10–1.51
3.24 to <3.49 kg	1.62	1.39–1.88
3.49 to <3.81 kg	1.84	1.59–2.14
≥3.81 kg	2.70	2.34–3.12
Rapid weight gain		
No (≤0.67 SD ΔWFA *z* score)	Ref	—
Yes (>0.67 SD ΔWFA *z* score)	4.21	3.83–4.62
Type of delivery		
Normal	Ref	—
Instrumental	1.11	1.00–1.24
Caesarean	1.07	0.92–1.24

SUPPLEMENTAL TABLE 8 Continued

Potential Risk Factors	Unadjusted OR	95% CI
Maternal age		
<20 y	Ref	—
20 to 29 y	0.99	0.78–1.26
30 to 39 y	0.99	0.78–1.25
≥40 y	0.90	0.66–1.24
Maternal prepregnancy BMI		
<18.5 kg/m^2	Ref	—
18.5 to <25 kg/m^2	1.64	1.29–2.10
25 to <30 kg/m^2	2.59	2.00–3.35
≥30 kg/m^2	3.23	2.46–4.25
Paternal BMI		
<18.5 kg/m^2	Ref	—
18.5 to <25 kg/m^2	1.18	0.61–2.27
25 to <30 kg/m^2	1.78	0.93–3.40
≥30 kg/m^2	2.37	1.22–4.58
Maternal smoking in pregnancy		
No	Ref	—
Yes	1.23	1.11–1.36
Maternal alcohol consumption		
Never	Ref	—
Monthly	1.06	0.94–1.20
Weekly	1.06	0.94–1.19
Daily	0.78	0.62–0.99
Maternal feelings of depression		
No	Ref	—
Yes	1.05	0.95–1.16
Maternal health		
Poor	Ref	—
Fair	0.88	0.66–1.17
Good	0.85	0.65–1.12
Excellent	0.80	0.61–1.05
Maternal diabetes		
No	Ref	—
Yes	1.36	1.02–1.81
Ever breastfed		
No	1.22	1.11–1.34
Yes	Ref	—
Breastfeeding duration		
<1 mo	Ref	—
1 to 2 mo	1.00	0.86, 1.16
3 to 4 mo	1.11	0.94–1.31
5 to 6 mo	1.09	0.90–1.32
7 to 8 mo	0.85	0.72–0.99
≥9 mo	0.81	0.59–1.11
Ever formula fed		
No	Ref	—
Yes	1.44	1.16–1.80
Introduction of solid food		
1 to 2 mo	Ref	—
3 to 4 mo	0.65	0.47–0.89
5 to 6 mo	0.63	0.45–0.89
7 to 8 mo	0.66	0.42–1.03
9 to 10 mo	0.45	0.15–1.37
Unhappy feeding interrupted		
Never	Ref	—
Rarely	0.96	0.85–1.07
Usually not	0.99	0.86–1.13
Often	1.00	0.86–1.17
Always	1.18	0.97–1.42
Not sure	1.04	0.81–1.34

SUPPLEMENTAL TABLE 8 Continued

Potential Risk Factors	Unadjusted OR	95% CI
Makes a fuss going to sleep		
Never	Ref	—
Rarely	1.04	0.89–1.20
Usually not	1.00	0.86–1.17
Often	1.09	0.93–1.27
Always	1.05	0.88–1.25
Not sure	1.04	0.79–1.37
Makes a fuss after waking		
Never	Ref	—
Rarely	0.94	0.84–1.05
Usually not	0.93	0.82–1.06
Often	0.86	0.74–1.00
Always	0.85	0.70–1.04
Not sure	0.93	0.71–1.21
Upset when not getting things		
Never	Ref	—
Rarely	0.95	0.81–1.12
Usually not	0.97	0.82–1.15
Often	0.93	0.79–1.10
Always	0.95	0.79–1.17
Not sure	0.92	0.70–1.20
Infant can sit up		
Not yet	Ref	—
Once or twice	1.38	0.85–2.24
Often	1.66	1.14–2.41
Infant can stand holding on		
Not yet	Ref	—
Once or twice	0.98	0.83–1.16
Often	0.93	0.83–1.04
Infant can grab objects		
Not yet	Ref	—
Once or twice	0.44	0.13–1.52
Often	0.68	0.24–1.97
Infant can hold objects		
Not yet	Ref	—
Once or twice	1.01	0.76–1.34
Often	1.03	0.82–1.30
Infant can walk		
Not yet	Ref	—
Once or twice	1.05	0.89–1.25
Often	1.01	0.83–1.23

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