Prediction of obesity from infancy to adolescence
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ABSTRACT
Aim: To examine the development of childhood obesity and to determine the earliest age when estimating body mass using only weight and height data is associated with a corresponding estimate at the age of 15.
Methods: Subjects included are all children born in 1991 in Östergötland County, Sweden. Weight and height data collected during regular check-ups at well-child centres and school health care assessments up to 15 years of age were assembled from health records. Correlations between childhood estimates of body mass and the body mass index (BMI) at 15 years of age were computed pairwise. Correlations with r > 0.5 were defined as reliably strong.
Results: Complete data were available for 3579 children (62%). Fewer girls (2.6%; C.I. 1.9–3.3) than boys (4.6%; C.I. 3.7–5.5) were obese at 15 years of age. Correlations with BMI at 15 years of age were strong (significantly higher than 0.5) from 5 years of age. Only 23% of girls and 8% of boys found to be obese at 5 years of age were of normal weight at the age of 15.
Conclusion: From 5 years of age, point estimates of body mass using only weight and height data are strongly associated with BMI at the age of 15. More data sources are needed to predict weight trajectories in younger children.

INTRODUCTION
It has been established that raised BMI in late adolescence is associated with overweight and obesity as adults (1). Recent studies have suggested also that adult body weight is influenced by body mass developments before adolescence and that overnutrition in early life might programme risks for early onset of cardiovascular and metabolic disease (2). In other words, present research indicates that the longer a child remains at a healthy weight, the more likely it is that he or she can avoid diseases in adulthood associated with obesity (3). Therefore, from a public health perspective, there are reasons for providing support at as early an age as possible to individuals prone to overweight and obesity. However, the age when such prevention programmes should be initiated has not been determined.

One way to decide at what age obesity prevention programmes should be initiated for children is to identify the earliest age when their BMI measurements predict their adult body composition. We set out to determine at what age an estimate of body mass using weight and height data is reliably associated with the corresponding estimate in late adolescence, both for boys and girls. Patterns of changes in body mass in early childhood are so we decided not to calculate BMI from birth. Rather, we used the ponderal index (PI) (kg/m^3) as the measure of body mass from birth to 1.5 years of age (4). The results will be used at the population level for planning obesity prevention programmes at well-child health centres and school health services.

SUBJECTS AND METHODS
The primary study population (n = 5778) consisted of all children born in 1991 and still living in Östergötland

Key notes
- There are reasons for providing support at as early an age as possible to children prone to overweight and obesity.
- In a cohort study representing all children born 1991 in a Swedish county, a strong correlation was found between childhood body mass index (BMI) measurements from 5 years of age.
- Point estimates of body mass based on weight and height data can be used for planning obesity prevention programmes from 5 years of age.

Abbreviations
BMI, Body mass index; CI, Confidence interval; EU, European Union; IOTF, International Obesity Task Force; km^2, Square kilometre.
County 2007. The county, situated in the south-east of Sweden, has a total population of 420,000 and an area of 9,979 km². The final study cohort was defined to include all those children who had participated in regular measurements of weight and height at well-child health centres and school health care assessments.

Data collection
Data on weight and height were gathered from the children's well-child health centres records at birth, 1½ years, 2½ years and 5 years. Thereafter, weight and height data were gathered from records of the school health services at 7, 10 and 15 years of age. At the 72 senior level schools in the county, the registration of weight and height took place either in grade 8 or 9 (at age 14–15 years).

Data analyses
The PI was used as the measure of body mass for each child and set of measurements from birth to 1.5 years of age. The BMI was calculated from 2.5 to 15 years. Overweight and obesity were defined according to the recommendation of the International Obesity Task Force (IOTF). From two and a half years of age, the BMI values were also categorized into age and gender adjusted classes (5).

Correlations between the PI/BMI recorded from birth to 10 year of age (at 0, 1.5, 2.5, 5, 7 and 10 years of age) and the BMI at 15 years of age were computed pairwise. Measurements of BMI within the same subject are prone to be correlated with some degree. To determine when this progression exhibited saturation, we used limit values suggested by the Cohen scale (6). This scale defines a correlation with $r = 0.5–1.0$ as ‘large’, $r = 0.3–0.5$ as ‘moderate’, and a correlation of $r = 0.1–0.3$ as ‘small’.

All statistical analyses were performed with SPSS version 17.0, except inference for correlations where Fischer's z-transformation was used. Nonoverlapping 95% confidence intervals (95% C.I.) were considered as significant differences.

RESULTS
From the 5778 children born in 1991 still resident in the county in 2007, 3579 (62%) provided complete data from birth to 15 years of age. About 1718 (48%) were girls and 1861 (52%) boys. The most common reason (65%) for non-participation was absenteeism at the 2.5 year check-up, possibly because this check-up was not combined with the vaccination programme. Remaining reasons for missing data included absenteeism from other child health service visits, weight and height data being accidently not noted in the child's record, and that child or parents declined to consent to using their PI/BMI data in the study. Data were also missing for a few individuals with physical or mental disorder or with protected identity. The median age of the participating children was close to the expected age at the measurements at 1.5, 2.5, 5 and 7 years of age. At 10 years of age measurement, the median age was 10.5 years, and the median age at 15 years of age measurement was 14.5 years (Table 1).

Prevalence of overweight and obesity
At the age of 15, fewer girls (2.6%; 95% C.I. 1.9%–3.3%) than boys (4.6%; 95% C.I. 3.7–5.5%) were obese but there was no statistically significant difference in the prevalence of being overweight between boys and girls at 15 years of age (12.9% for girls and 14.1% for boys). For both girls and boys, the prevalence of overweight increased from age seven to 10 years and then decreased from 10 to 15 years of age (Table 2).

Table 1 Age of final study participants (n = 3579) at each measurement displayed by sex

<table>
<thead>
<tr>
<th>Expected age</th>
<th>1.5</th>
<th>2.5</th>
<th>5</th>
<th>7</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Girls</td>
<td>Boys</td>
<td>Girls</td>
<td>Boys</td>
<td>Girls</td>
<td>Boys</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.5</td>
<td>0.5</td>
<td>1.5</td>
<td>1.5</td>
<td>4.2</td>
<td>4.0</td>
</tr>
<tr>
<td>Median</td>
<td>1.5</td>
<td>1.5</td>
<td>2.5</td>
<td>2.5</td>
<td>5.2</td>
<td>5.1</td>
</tr>
<tr>
<td>Maximum</td>
<td>2.5</td>
<td>2.1</td>
<td>3.7</td>
<td>3.8</td>
<td>6.8</td>
<td>6.8</td>
</tr>
<tr>
<td>n</td>
<td>1718</td>
<td>1861</td>
<td>1718</td>
<td>1861</td>
<td>1718</td>
<td>1861</td>
</tr>
</tbody>
</table>

Table 2 Prevalence of overweight and obesity displayed by age and sex

<table>
<thead>
<tr>
<th>Age</th>
<th>Overweight</th>
<th></th>
<th></th>
<th></th>
<th>Obesity</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Girls</td>
<td>(95% CI)</td>
<td>Boys</td>
<td>(95% CI)</td>
<td>Girls</td>
<td>(95% CI)</td>
<td>Boys</td>
</tr>
<tr>
<td>2.5</td>
<td>12.5</td>
<td>(11.0–14.0)</td>
<td>11.8</td>
<td>(10.4–13.8)</td>
<td>2.2</td>
<td>(1.5–2.9)</td>
<td>2.1</td>
</tr>
<tr>
<td>5.0</td>
<td>12.3</td>
<td>(10.8–13.8)</td>
<td>9.4</td>
<td>(8.1–10.7)</td>
<td>3.2</td>
<td>(2.4–4.0)</td>
<td>2.1</td>
</tr>
<tr>
<td>7.0</td>
<td>13.9</td>
<td>(12.4–15.4)</td>
<td>11.1</td>
<td>(9.8–12.4)</td>
<td>3.4</td>
<td>(2.6–4.2)</td>
<td>3.6</td>
</tr>
<tr>
<td>10.0</td>
<td>17.3</td>
<td>(15.7–18.9)</td>
<td>16.6</td>
<td>(15.1–18.1)</td>
<td>3.2</td>
<td>(2.4–4.0)</td>
<td>4.2</td>
</tr>
<tr>
<td>15.0</td>
<td>12.9</td>
<td>(11.4–14.4)</td>
<td>14.1</td>
<td>(12.6–15.6)</td>
<td>2.6</td>
<td>(1.9–3.3)</td>
<td>4.6</td>
</tr>
</tbody>
</table>
Correlations between growth characteristics
The correlation between PI/BMI measurements and BMI at 15 years of age was strong (significantly higher than \( r = 0.5 \)) from 5 years of age. The correlation pattern was similar between the sexes, except at 5 years when the girls displayed greater correlation (Table 3). Reviewing the individual data, 23% of the girls and 8% of the boys classified as obese at 5 years of age were found to be normal weight at the age of 15. Only 6% of those obese at 5 years of age among both sexes were of normal weight at the age of 10.

Table 3. PI/BMI development and correlations between point estimates of PI/BMI with BMI at 15 years of age displayed by gender. PI was calculated to 1.5 years of age.

<table>
<thead>
<tr>
<th>Age</th>
<th>PI/BMI (mean) (95% CI)</th>
<th>r (95% CI)</th>
<th>PI/BMI (mean) (95% CI)</th>
<th>r (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth</td>
<td>0.2753 (0.2736–0.2770)</td>
<td>0.04 (-0.001–0.092)</td>
<td>0.2717 (0.2704–0.2730)</td>
<td>0.08 (0.036–0.120)</td>
</tr>
<tr>
<td>1.5</td>
<td>0.2508 (0.2499–0.2517)</td>
<td>0.25 (-0.203–0.292)</td>
<td>0.2069 (0.2061–0.2077)</td>
<td>0.28 (0.188–0.274)</td>
</tr>
<tr>
<td>2.5</td>
<td>16.43 (16.37–16.49)</td>
<td>0.41 (0.370–0.449)</td>
<td>16.71 (16.65–16.77)</td>
<td>0.33 (0.288–0.370)</td>
</tr>
<tr>
<td>5</td>
<td>15.82 (15.75–15.89)</td>
<td>0.63 (0.601–0.658)</td>
<td>15.90 (15.83–15.97)</td>
<td>0.57 (0.538–0.600)</td>
</tr>
<tr>
<td>7</td>
<td>16.25 (16.15–16.35)</td>
<td>0.70 (0.675–0.723)</td>
<td>16.53 (16.24–16.42)</td>
<td>0.68 (0.655–0.704)</td>
</tr>
<tr>
<td>10</td>
<td>18.14 (18.00–18.28)</td>
<td>0.81 (0.793–0.826)</td>
<td>18.25 (18.11–18.39)</td>
<td>0.79 (0.772–0.807)</td>
</tr>
<tr>
<td>15</td>
<td>20.76 (20.60–20.92)</td>
<td>1</td>
<td>20.62 (20.46–20.78)</td>
<td>1</td>
</tr>
</tbody>
</table>

BMI, body mass index.

**DISCUSSION**
We set out to determine the age for boys and girls when PI/BMI values begin to be associated with the corresponding measurements in late adolescence. We found a strong correlation (\( r > 0.5 \)) between the intra-individual measurements from 5 years of age onwards. We also found that, in our study cohort, 23% of the girls and 8% of the boys defined as obese at age 5 were of normal weight at the age of 15. Combining the facts that so few individuals had returned to normal weight from the age of 5 and that intra-individual BMI values were strongly correlated from 5 years up to 15 years of age, we conclude that there are reasons for offering population-based interventions systematically from 5 years of age. This recommendation is supported by the reports from Kim et al. (7) who found that prevention at 5–8 years of age was more successful compared with when the children had reached 11–13 years. We consider our study cohort is representative in that 14% were overweight and 4% obese at 15 years of age. The proportion of those overweight was highest (17%) at the age of 10. The proportion of obesity was relatively constant, 2–3%, through the school years for girls, while obesity in boys is steadily increasing over time. These findings are in concordance with previous Swedish cross-sectional studies. The prevalence of overweight and obesity among boys is often higher than in girls and higher in the younger age (4, 10 years) compared with adolescents (15–16 years) (8–11).

There are relatively few longitudinal cohort studies of BMI development in Swedish children. Data from a cohort (n = 5650) born 1973–75 in Gothenburg covering annual BMI values from 2 years of age to 15 years of age have been reported (12). A similar data set was collected from children (n = 2591) born in the southern suburbs of Stockholm in 1985–87. A comparison of the BMI distribution from 2 years of age to 15 years of age between these cohorts showed that from the age of 7, the children born 1985–87 had higher BMI mean values than their counterparts born 12 years earlier (13). The authors concluded that school-aged children may be more susceptible to ‘obesogenic’ environmental exposures than younger children.

Even though it included both urban and rural children, our study cohort displayed a pattern of BMI distribution during childhood similar to the cohort born in suburban Stockholm in 1985–1987. Thus, despite the fact that we used a different method for our analysis (correlation strength between measurement age), we found that it should be possible to trace weight trajectories from preschool age. From the perspective of eventual health risks as adults, it would be worthwhile to identify at an early age and offer interventions to those relatively few children with substantially increased risk of maintaining obesity in adulthood, but also at the same time not to intervene when it is not necessary. To identify children at risk, a simple decision protocol that can be used at well-child centres and in school health care is needed to identify individuals who are on trajectories that will lead to persisting obesity (14). Correspondingly, research is needed on cost-effective treatment programmes for young obese children. Present evidence suggests that long-term family based behavioural interventions can achieve lasting weight reduction in this category of children (15).

The strength of this study is that we have followed one cohort of children in a defined geographic area in Sweden from birth to 15 years of age. The data on height, weight and the exact measurement date originate from routine examinations at well-child health centres and school health services, where all examinations were performed by trained nurses. One limitation of this study is that we only followed the children to 15 years of age. However, Warndle et al. (8) found that obesity already existing in early adolescence (11 years of age) is a clear indication for persisting obesity, and Whitaker et al. (1) have found that four of five obese teenagers remain obese in adulthood. We recognize that
BMI was not originally designed for the purpose of tracing obesity in growing children. Alternative classifications of BMI measurements in children have been used, e.g. relative classifications where children over the 80th percentile for their respective age and gender are classified as overweight and those over the 95th percentile as obese (16–18). However, the IOTF criteria (5) are based on an international cohort consisting of almost 200,000 individuals and relate to the risk for adult morbidity. We chose to present our results according to these criteria to make the broadest comparisons possible.

In conclusion, in our cohort study representing all children born 1991 in a Swedish county, we found a strong intra-individual correlation ($r > 0.5$) between childhood BMI measurements from 5 years of age and that few children who were obese at preschool age were of normal weight as adolescents. These findings indicate that point estimates of body mass based on weight and height data can be used for planning obesity prevention programmes at the population level from 5 years of age. They suggest also that point estimates of PI/BMI are insufficient for planning obesity interventions in younger children. Further research is warranted to combine these estimates with other data sources and analytic methods in this age group.

ACKNOWLEDGEMENTS
We want to thank all nurses at the school health care centres for their participation.

CONFLICT OF INTEREST
None.

References