Objectives: To systematically analyze growth data from infant health maintenance records to characterize infant weight gain increasing risk for childhood overweight, and to identify additional information from those records that could refine risky infant weight gain as a screening tool.

Design: Retrospective cohort study.

Setting: A pediatric office in central Pennsylvania.

Participants: Children aged 6 to 8 years (n = 129) born in 2000 or later who attended health maintenance visits.

Main Exposures: Risky infant weight gain was a cutoff selected after considering its sensitivity and specificity during the interval best predicting childhood overweight risk as determined with receiver operating characteristic curve analysis. We identified demographic, growth pattern, and parental feeding choice differences between at-risk infants who did and did not become overweight children.

Main Outcome Measure: Childhood overweight, defined as a sex- and age-specific body mass index of the 85th percentile or higher at ages 6 to 8 years according to 2000 Centers for Disease Control and Prevention growth charts.

Results: Childhood overweight prevalence was 24.8%. At-risk infants gained at least 8.15 kg from ages 0 to 24 months. While 31.4% of at-risk infants became overweight children, 68.6% were resilient. At-risk, resilient participants had parents with more education, had lower weight gain from ages 18 to 24 months and 0 to 24 months and a smaller area under the weight-gain curve from ages 0 to 24 months, were more often exclusively breastfed for 6 months or longer, and were introduced to solid foods later than at-risk, overweight participants.

Conclusions: While most researchers would not recognize weight gain of 8.15 kg or more from ages 0 to 24 months as rapid growth, it was a fair screening tool for childhood overweight in our sample and had the potential to be refined using information about demographic characteristics, growth patterns, and parental feeding choices.
providers within the context of infant health maintenance visits. For example, demographic information such as parental education might give insight about an infant’s socioeconomic status, and there is a disproportionate burden of childhood overweight among groups with lower socioeconomic status. Mother’s parity would be useful to note because infants of first-time mothers have growth velocities resulting in larger childhood body size. Size at birth (being female or having a longer gestation or higher birth weight) might increase risk because a set amount of infant weight gain is proportionally more to a girl than to a boy and because a larger newborn gaining a set amount of infant weight would be a larger infant than a smaller newborn gaining the same amount of infant weight. Similarly, infants gaining more weight during specific periods such as early infancy might have increased risk of subsequent overweight. Finally, parental feeding choices such as a later introduction of solid foods, a longer breastfeeding duration, and exclusive breastfeeding for 6 months or longer might protect infants from subsequent overweight because these practices are aligned with feeding recommendations from the World Health Organization and the AAP. Such factors might allow clinicians to screen infants for childhood overweight risk and target prevention efforts during routine medical visits.

This study had 2 objectives. The first was to characterize risky infant growth by determining the infant weight-gain duration optimally discriminating between overweight and nonoverweight children and then selecting a weight-gain cutoff during that interval for use in assigning at-risk status, taking into account the sensitivity and specificity of the cutoff. We assessed absolute change in infant weight as opposed to other measures of infant growth for 2 reasons. First, infant length measures taken in a clinical setting (and therefore infant growth measures using length such as weight for length or ponderal index) are less accurate than infant weight measures. In addition, previous research has found infant weight gain to be a better predictor of childhood overweight than change in infant length, body mass index (BMI, calculated as weight in kilograms divided by height in meters squared), and ponderal index. Our second objective was to identify factors that differed between at-risk infants who did and did not become overweight children that could be used to improve the use of infant growth as a screening tool for childhood overweight. Our analyses focused on the demographic characteristic, growth pattern, and feeding choice information available to pediatric medical providers from infant health maintenance visits. The study was reviewed and approved by the Pennsylvania State University College of Medicine Institutional Review Board, Hershey.

**METHODS**

**PARTICIPANTS**

This was a retrospective study of a cohort of children seen for routine health maintenance visits at a primary care pediatric office associated with a large academic medical center in central Pennsylvania. The pediatric office is a free-standing clinic and the largest outpatient facility of its kind in the area. It serves families living in urban, suburban, and rural communities and is the only practice in the area accepting Medicare as well as a variety of other insurances.

The medical center’s computerized scheduling database provided the means for our selection of 129 patients meeting our inclusion criteria. These patients were full-term (gestational age >37 and <42 weeks) singleton children born in 2000 or later who lacked health problems requiring attention from the neonatal intensive care unit or that would potentially affect normal growth. They had health maintenance medical records from birth, ages 6, 12, 18, and 24 months, and sometime between ages 6 and 8 years.

**DATA**

For each participant, we obtained data from the postdelivery hospital discharge form (sex, birth date, gestational age, birth weight, and mother’s parity), the family history record (parental education), each well-baby care visit record (visit date, weight, and descriptive information about parental feeding choices at 1 week and at 1, 2, 4, 6, 9, 12, 15, 18, and 24 months), and the earliest well-child care visit record between ages 6 and 8 years (visit date, weight, and height) as available. Infant nude weight was recorded to the nearest 0.01 kg using a digital scale (Olympic Smart Scale Model 60; Natus Medical Inc, San Carlos, California). Childhood weight and height were recorded to the nearest 0.01 kg and 0.1 cm, respectively, using a digital scale with attached stadiometer (Seca 706 Digital Uniscale; Seca GmbH and Co KG, Hamburg, Germany) while children wore light clothing and no shoes. All measurements were made by nurses trained to measure infants and children.

**CHILDHOOD OVERWEIGHT AS OUTCOME VARIABLE**

Childhood overweight was defined as a sex- and age-specific BMI of the 85th percentile or higher at age 6, 7, or 8 years according to 2000 Centers for Disease Control and Prevention growth charts. We calculated childhood BMI percentiles for each participant using SAS version 9.2 statistical software (SAS Institute, Inc, Cary, North Carolina) and an SAS code available on the Centers for Disease Control and Prevention Web site requiring the weight, height, sex, and actual age of each participant at their well-child care visit for its calculations.

**RISKY INFANT GROWTH AS EXPOSURE VARIABLE**

Receiver operating characteristic (ROC) curve analyses (MedCalc version 9; MedCalc Software, Mariakerke, Belgium) were used to determine what duration of infant weight gain (birth to age 6, 12, 18, or 24 months) must be observed to best screen for later childhood overweight. For each infant weight-gain interval tested, the area under the ROC curve was the proportion of time in which the infant weight gain of a randomly selected participant with childhood overweight exceeded that of a randomly selected participant without childhood overweight. We considered the infant weight-gain interval resulting in the largest area under the ROC curve as the optimal screening interval.

The ROC curve analyses were also used to help us select a threshold amount of weight gain during the optimal screening interval to use in assigning at-risk status with respect to the outcome. The weight-gain cutoff with the best combined sensitivity and specificity served as a starting point from which we lowered our threshold to capture the 5 false-negative cases as true-
positives. Participants were defined as being at risk if they gained weight equal to or greater than our selected threshold during the optimal screening interval. At-risk infants who developed childhood overweight were defined as being at risk and overweight, and at-risk participants who did not become overweight in childhood were defined as being at risk and resilient.

FACTORS THAT PROTECT AT-RISK INFANTS

We assessed differences in demographic characteristics, feeding behaviors, and growth patterns between at-risk, overweight participants and at-risk, resilient participants to find possible explanations for their differential outcomes. Similar proportions of at-risk, overweight participants and at-risk, resilient participants had missing data for the factors examined. Any factors significantly related to at-risk, resilient status were considered protective. We used $\chi^2$ tests of independence and independent samples $t$ tests to assess our 1-tailed hypotheses, and statistical significance for all tests was set at $P < .05$.

The demographic characteristics we assessed were participant’s sex, mother’s and father’s education (≤high school vs >high school), and combined parental education (≥1 parent with ≤high school education vs both parents with >high school education). We hypothesized that being male and having parents with more education would be protective. We assessed the parental feeding choices of solid food introduction (first parental report of solid food feeding), breastfeeding duration (last parental report of breast milk feeding), and exclusive breastfeeding (parental report of breast milk feeding and no formula) for 6 months or longer. We hypothesized that a later introduction of solid foods, a longer breastfeeding duration, and exclusive breastfeeding for 6 months or longer would be protective.

### RESULTS

The study cohort consisted of 129 children from central Pennsylvania born in 2000 or later. About half of the participants were male (Table 1). The mean participant birth weight fell within the normal birth-weight range according to the 2000 Centers for Disease Control and Prevention growth curve. The mean breastfeeding duration was 4.57 months, and only about a third of the participants were exclusively breastfed for the recommended 6 or more months; however, solid foods were introduced at an average of 6.03 months. A fourth of the children in the cohort were overweight at an average age of 6.63 years.

### PARTICIPANT CHARACTERISTICS AND OUTCOME VARIABLE

All tested infant weight-gain intervals discriminated between overweight and nonoverweight children significantly better than random chance (Table 2). The interval from ages 0 to 24 months had the largest area under the ROC curve (Figure 1), discriminating between overweight and nonoverweight children at ages 6 to 8 years 77% (95% confidence interval [CI], 68%-84%) of the time. In addition, the areas under the weight-gain ROC curves from ages 0 to 6, 0 to 12, and 0 to 18 months were not significantly different from one another when compared in a pairwise fashion (data not shown); however, each differed significantly from the area under the weight-gain ROC curve from ages 0 to 24 months ($P = .009$, .02, and .03, respectively).

### EXPOSURE VARIABLE OF RISKY INFANT GROWTH

From ages 0 to 24 months, weight gain of 9.01 kg or more had the best combined sensitivity (84.4%; 95% CI,
Monitoring growth is a central function of infant health maintenance visits, rendering infant weight gain a key variable for the early identification of individuals at risk for childhood overweight. Certainly, infant weight gain, which substantial evidence shows is related to childhood overweight, has potential as a screening tool; however, it lacks precision because infants with high weight gain often do not become overweight children. Therefore, we sought to both characterize risky infant weight gain through systematic analyses and identify additional information available from infant health maintenance visits that clinicians could use to more accurately identify individuals at risk for future childhood overweight when risky infant growth occurs.

In our cohort, it was risky to gain 8.15 kg or more from ages 0 to 24 months. The optimal screening interval of ages 0 to 24 months was the longest interval tested. This is consistent with the findings by Toschke et al., who first used ROC curve analysis to assess infant growth and childhood overweight risk. It is likely that longer intervals provide statistically better screening capabilities than shorter intervals for 2 reasons. First, longer intervals from birth terminate at an age closer to that of the outcome measure than do shorter intervals, and it follows that differences between participants identified at age 24 months are more likely than those identified earlier in infancy to persist into childhood. Second, longer intervals increase the variability in the amount of weight gained between participants, making differences in infant growth relating to subsequent overweight more apparent. While observing 24 months of weight gain optimizes screening accuracy, it also delays prevention efforts. Clinicians may find this unacceptable because at age 24 months, increasing weight status already increases risk of overweight in childhood and beyond.

Our weight-gain cutoff of 8.15 kg or more from ages 0 to 24 months did not maximize sensitivity and speci-
Table 3. Differences in Potential Refining Factors Between At-Risk Participants Who Are Resilient and At-Risk Participants Who Are Overweight

<table>
<thead>
<tr>
<th>Factor</th>
<th>At-Risk, Resilient Participants (n=70)</th>
<th>At-Risk, Overweight Participants (n=32)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male, No. (%)</td>
<td>40 (57.1)</td>
<td>13 (40.6)</td>
<td>.06</td>
</tr>
<tr>
<td>Parents with &gt;high school ed. No. (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mother a</td>
<td>42 (72.4)</td>
<td>15 (55.6)</td>
<td>.06</td>
</tr>
<tr>
<td>Father b</td>
<td>37 (69.8)</td>
<td>13 (54.2)</td>
<td>.09</td>
</tr>
<tr>
<td>Both c</td>
<td>36 (66.7)</td>
<td>12 (46.2)</td>
<td>.04</td>
</tr>
<tr>
<td>Parental feeding choices</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid food introduction, mean (SD), mo d</td>
<td>6.49 (2.80)</td>
<td>5.10 (1.80)</td>
<td>.007</td>
</tr>
<tr>
<td>Breastfeeding duration, mean (SD), mo e</td>
<td>4.85 (5.08)</td>
<td>3.29 (4.58)</td>
<td>.09</td>
</tr>
<tr>
<td>Exclusively breastfed for ≥6 mo, No. (%) f</td>
<td>25 (37.3)</td>
<td>6 (18.8)</td>
<td>.03</td>
</tr>
<tr>
<td>Growth patterns</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birth weight, mean (SD), kg</td>
<td>3.52 (0.44)</td>
<td>3.62 (0.47)</td>
<td>.16</td>
</tr>
<tr>
<td>Gestational age, mean (SD), wk g</td>
<td>39.47 (1.22)</td>
<td>39.69 (1.28)</td>
<td>.23</td>
</tr>
<tr>
<td>Primiparous mother, No. (%) h</td>
<td>29 (43.9)</td>
<td>14 (46.7)</td>
<td>.40</td>
</tr>
<tr>
<td>Weight gain during interval, mean (SD), kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-6 mo</td>
<td>4.49 (0.73)</td>
<td>4.68 (0.90)</td>
<td>.14</td>
</tr>
<tr>
<td>6-12 mo</td>
<td>1.90 (0.52)</td>
<td>2.03 (0.77)</td>
<td>.15</td>
</tr>
<tr>
<td>12-18 mo</td>
<td>1.61 (0.61)</td>
<td>1.69 (0.57)</td>
<td>.26</td>
</tr>
<tr>
<td>18-24 mo</td>
<td>1.43 (0.64)</td>
<td>1.75 (0.72)</td>
<td>.01</td>
</tr>
<tr>
<td>0-24 mo</td>
<td>9.43 (0.92)</td>
<td>10.15 (1.21)</td>
<td>.002</td>
</tr>
<tr>
<td>Area under the weight-gain curve from ages 0-24 mo, mean (SD), kg-d</td>
<td>4616.47 (628.26)</td>
<td>4854.11 (757.80)</td>
<td>.05</td>
</tr>
</tbody>
</table>

a Data on mother’s education were missing for 15.6% of at-risk, overweight participants and 17.1% of at-risk, resilient participants.

b Data on father’s education were missing for 25.0% of at-risk, overweight participants and 24.3% of at-risk, resilient participants.

c Data on combined parental education were missing for 18.8% of at-risk, overweight participants and 22.9% of at-risk, resilient participants.

d Data on solid food introduction were missing for 31.1% of at-risk, overweight participants and 10.0% of at-risk, resilient participants.

e Data on breastfeeding duration were missing for 12.5% of at-risk, overweight participants and 15.7% of at-risk, resilient participants.

f Data on exclusive breastfeeding for 6 months or longer were missing for 4.3% of at-risk, resilient participants.

g Data on gestational age were missing for 22.9% of at-risk, overweight participants and 15.6% of at-risk, resilient participants.
h Data on mother’s parity were missing for 6.7% of at-risk, overweight participants and 5.7% of at-risk, resilient participants.

Growth patterns: We characterized infant growth by the area under the weight-gain curve from ages 0-24 months, to assign risk for childhood overweight. This approach allows for earlier identification of factors modulating risk in at-risk infants prior to age 24 months to allow for earlier prevention efforts. Therefore, we identified 6 factors differing between at-risk individuals who did and did not go on to become overweight that have the potential to refine infant growth as a screening tool for childhood overweight: combined parental education, weight gain from ages 0 to 24 months, area under the weight-gain curve from ages 0 to 24 months, exclusive breastfeeding for 6 months or longer, and solid food introduction. Of these factors, the parental feeding choices provide clear opportunities for intervention by clinicians, and the growth pattern differences raise questions for future research.

Table 3. Differences in Potential Refining Factors Between At-Risk Participants Who Are Resilient and At-Risk Participants Who Are Overweight

The amount of infant growth we characterized as being risky is lower than the amounts other researchers have used. Toschke et al13 used the cutoff with the best combined sensitivity and specificity, which was 9.76 kg from ages 0 to 24 months, to assign risk for childhood overweight. Other researchers have characterized risk as rapid growth, often defined as upward centile line crossing on standard growth curves.23,24 A weight gain of 8.15 kg by age 2 years cannot be called rapid; in fact, many babies would track along a centile line or even experience downward centile line crossing. However, we feel it is appropriate to label our threshold as risky growth. Given the current high prevalence of childhood overweight, we assert that infant growth does not need to be rapid to be risky. This idea is supported by findings from the National Institute of Child Health and Human Development Study of Early Child Care and Youth Development, which found that normal infant growth is not without risk when studying recent cohorts.22 In addition, gaining 8.15 kg or more from ages 0 to 24 months was a fair screening tool in our study; the childhood overweight prevalence in the cohort was 24.8%, yet this increased to 31.4% in at-risk infants and decreased to 0.0% in non–at-risk infants.

However, we would prefer minimizing the false-positive cases to improve the positive predictive value of screening, and we find it important to identify factors modulating risk in at-risk infants prior to age 24 months to allow for earlier prevention efforts. Therefore, we identified 6 factors differing between at-risk individuals who did and did not go on to become overweight that have the potential to refine infant growth as a screening tool for childhood overweight: combined parental education, weight gain from ages 0 to 24 months, area under the weight-gain curve from ages 0 to 24 months, exclusive breastfeeding for 6 months or longer, and solid food introduction. Of these factors, the parental feeding choices provide clear opportunities for intervention by clinicians, and the growth pattern differences raise questions for future research.
The Expert Committee of the AAP has recommended “encouraging exclusive breastfeeding to 6 months of age and maintenance of breastfeeding after introduction of solid food to 12 months of age and beyond.”33 Breastfeeding, and especially exclusive breastfeeding, is likely to protect against childhood overweight through a variety of mechanisms,29,30 and an early introduction to solid foods has been shown to increase risk for childhood overweight.31,32 In our cohort, the AAP recommendations were protective. However, they are far from being the norm in the United States. Data from the Feeding Infants and Toddlers Study indicate that only 40% of infants aged 4 to 6 months consumed breast milk daily. This figure decreased to 14% in infants aged 12 to 14 months. In addition, solid foods were introduced before age 6 months in 94% of infants.33 Counseling parents about healthy infant feeding has been identified as an opportunity for pediatric medical providers to prevent childhood overweight34 and is recommended by the AAP.3

Differences in growth patterns between at-risk, resilient participants and at-risk, overweight participants raise ideas for future research. First, something happens between ages 18 and 24 months that causes significant growth differences. Perhaps differences in infant feeding or other lifestyle factors are causes. For infants aged 18 to 24 months, the largest percentage of calories comes from table foods, and Feeding Infants and Toddlers Study data reveal alarming trends among infants in this age group. For example, 75% of infants consume desserts and/or candy daily, and the most consumed vegetables are French fries.33 In addition, television viewing is an activity that one study reports 96% of infants aged 2 years do for an average of 15 hours weekly.35 Second, area under the weight-gain curve from ages 0 to 24 months may reveal something about the influence of infant growth trajectory on childhood overweight. Area under the weight-gain curve has been previously used to assess how gestational weight-gain patterns affect risk of postpartum weight retention,36 but to our knowledge it has not yet been used to assess the risk of infant weight-gain patterns. Area under the weight-gain curve takes into account both the amount (y-axis) and timing (x-axis) of growth, making the weight gained early in infancy accrue more kilograms than weight gained later in infancy. We investigated this possibility because studies have shown that weight gain in the first week of life can predict later overweight16 and because differences in weight-gain trajectories between formula-fed and breastfed infants emerge around ages 2 to 3 months.37 The fact that area under the weight-gain curve from ages 0 to 24 months differed between at-risk, overweight participants and at-risk, resilient participants when weight gain from ages 0 to 6, 6 to 12, and 12 to 18 months did not differ suggests that differences in early weight gain or growth trajectory are not easily detected. Perhaps, as Harrington et al18 suggest, the accrual of excess weight gain begins shortly after birth but at a rate undetectable until age 2 years.

It is premature to recommend that clinicians make use of our conclusions. Our findings must first be confirmed in studies of other current cohorts that are larger and more diverse than ours, clarified in well-controlled prospective studies that would lack the selection bias presented by retrospectively examining infants who attended health maintenance visits, and extended to determine how well the addition of refining factors actually improves infant weight gain as a screening tool for pediatric overweight. In addition, we acknowledge that the development of screening tools for childhood overweight, while important, will be useful to clinicians only if effective measures for preventing childhood overweight are researched more extensively.8 However, we are encouraged by the potential of early infant growth, in association with other early-life risk or protective factors, as a screening tool for childhood overweight. With further research, this approach to the early identification of individuals at risk for childhood overweight could fill a void in the complex and developing field of childhood overweight prevention.

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Author Contributions: Ms Gungor had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Gungor, Paul, Birch, and Bartok. Acquisition of data: Gungor, Paul, and Bartok. Analysis and interpretation of data: Gungor, Paul, Birch, and Bartok. Drafting of the manuscript: Gungor and Bartok. Critical revision of the manuscript for important intellectual content: Gungor, Paul, Birch, and Bartok. Statistical analysis: Gungor and Bartok. Obtained funding: Birch and Bartok. Administrative, technical, and material support: Paul and Bartok. Study supervision: Paul, Birch, and Bartok.

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Adolescence is perhaps nature’s way of preparing parents to welcome the empty nest. —Karen Savage and Patricia Adams, authors of The Good Stepmother