RESILIENCE IN THE FACE OF RISK:
FACTORS THAT PROTECT AGAINST CHILDHOOD OBESITY
WHEN RISKY INFANT GROWTH OCCURS

A Thesis in
Nutrition
By
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ABSTRACT

Objectives: To: a) conduct a systematic analysis of infant growth intervals in order to determine which interval best discriminated between overweight and non-overweight children, and what amount of infant growth during that interval was the best predictor of subsequent childhood overweight; and b) identify factors during infancy that might confer protective effects against the development of childhood overweight when risky infant growth occurs.

Design: Retrospective cohort study.

Setting: Central Pennsylvania.

Participants: Central Pennsylvanian children (n = 192) aged 6 to 8 years who were born in the year 2000 or later.

Outcome Measures: Childhood overweight at 6 to 8 years was defined as a sex- and age-specific body mass index at or above the 85th percentile according to the 2000 Centers for Disease Control and Prevention distribution. Receiver operating characteristic curve analysis determined the amount of infant weight gain best predicting childhood overweight. Infants gaining at least this amount of weight were considered at risk, and at risk infants who did not become overweight children were considered resilient. Differences in demographic characteristics, growth patterns, and feeding behaviors between at risk/overweight and at risk/resilient subjects were assessed.

Results: In our sample, 26.3% of children were overweight at age 6 to 8 years. At risk infants gained at least 8.57 kg from 0 to 24 months. While 39% of at risk infants became overweight
children, 61% were resilient. At risk/resilient subjects were more likely to be exclusively breastfed for at least 6 months and had a later introduction of solid foods than at risk/overweight subjects.

**Conclusions:** Feeding behaviors may provide resilience in the face of risk and protect individuals whose infant weight gain increases their likelihood for developing childhood overweight.
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CHAPTER 1

LITERATURE REVIEW

The Scope and Significance of Childhood Overweight and Obesity in America

The number of overweight and obese children in the United States is a public health concern. The term “obese” has been recommended for use when describing the weight status of children with a sex- and age-specific body mass index (BMI) at or above the 95th percentile, as their levels of body fat are likely to be high, while the term “overweight” has been recommended for use when describing the weight status of children with a BMI at or above the 85th percentile but below the 95th percentile.\(^1\) Data collected between 1971 and 1974 for the first National Health and Nutrition Examination Survey (NHANES) revealed that 4% of 6 to 11 year olds could be classified as obese according to the Center for Disease Control (CDC) distribution.\(^2\) The most recent NHANES data indicate that this figure has risen to 17% and that fully one-third of 6 to 11 year old children in the United States can be classified as either overweight or obese.\(^3\)

Preventing childhood overweight and obesity has both short term and long term public health importance. In the short term, many health problems are associated with childhood overweight and obesity. Childhood BMI is positively associated with increased fasting insulin levels, impaired glucose tolerance, insulin resistance and type 2 diabetes in childhood.\(^4,5\) Overweight and obese children are also more likely to have cardiovascular risk factors, such as elevated diastolic and systolic blood pressure and triglycerides and lower HDL.\(^4,5\) The risk of
asthma, gallstones, back pain, chronic inflammation, gastroesophageal reflux, steatohepatitis, sleep apnea, orthopedic conditions such as slipped capital femoral epiphysis and Blount’s disease, and neurological conditions such as idiopathic intracranial hypertension are all increased in overweight and obese children.4, 5

The short term psychosocial consequences of childhood overweight and obesity are also considerable. Negative stereotypes about overweight and obese people pervade American society, even among children. For example, overweight and obese children are more likely to be perceived as having lower physical and cognitive abilities and they are more likely to be teased and bullied.4 Anxiety and depression are associated with childhood overweight and obesity, and overweight and obese children have lower levels of self-esteem than those of average-weight children.4, 5 One study determined that obese children have a reduced quality of life across “physical, psychosocial, emotional, social and school functioning” domains using a pediatric quality of life inventory.6 Specifically, the inventory indicated that obese children have a quality of life similar to that of children diagnosed with cancer.

Research has consistently established that overweight and obesity during childhood track into adolescence and adulthood.7 Therefore, the long term health and psychosocial consequences of childhood overweight and obesity are very serious as well. Childhood BMI is positively associated with risk for heart disease, hypertension, high cholesterol, type 2 diabetes, polycystic ovary syndrome (in women), and various cancers later in life.4 Such associations have led to the prediction of a 2 to 5 year reduction in life expectancy in the United States5 and the hypothesis that today’s youth may live less healthy and shorter lives than those of their
In addition, childhood overweight and obesity are associated with disordered eating, including anorexia nervosa and bulimia nervosa, in adolescence and adulthood (especially in women), and overweight adolescent females complete fewer years of school, are less likely to be accepted into college and be married, and have lower household incomes as adults.4

The short term economic costs of childhood overweight and obesity have not been widely studied. From 1997 to 1999, the national annual hospital cost of childhood overweight and obesity was estimated to be $110 million.4 Considering the economic burden of obesity in all Americans is even more striking. In 1995, the direct medical cost of obesity the United States was estimated to be $70 billion.4

Clearly, there is strong evidence for the need to support measures aimed at decreasing the prevalence of childhood overweight and obesity. Unfortunately, the treatment of overweight and obesity is difficult and treatment programs have not been shown to be particularly effective, especially long-term.9 Therefore, obesity prevention is critical and it should be a public health priority to study the risk factors for childhood overweight and obesity.

**Infant Growth is Related to Childhood Overweight and Obesity**

A growing body of research is aimed at investigating very early life risk factors for childhood overweight and obesity. Infancy has been called a “critical period” for the development of childhood overweight and obesity because physiological changes during infancy “may have an increased or enduring effect on the physiology of weight gain.”10 Increase in body size occurs more rapidly during infancy than during any other period outside of
the womb. Infants following a CDC growth curve typically double their birth weight by about 5 months of age and triple it by the time they are one year old.

Many investigators have studied whether certain patterns of infant growth are predictive of childhood weight status. In the 1970’s, two studies\textsuperscript{11, 12} established that rapid growth in infancy predicted increased weight-for-height measures in childhood. Since that time, further studies have confirmed the association and additionally established associations between rapid infant growth and overweight and obesity in adolescents and adults.\textsuperscript{13-16} In a 2005 review article of rapid growth research, Monteiro \textit{et al.}\textsuperscript{14} found that “most studies showed a positive association between rapid growth and overweight, obesity, or other anthropometric measures.” More specifically, a review article by Baird \textit{et al.}\textsuperscript{13} reported that “odds ratios of obesity in children who grew more rapidly in infancy compared with those who grew less rapidly ranged between 1.06 and 5.7.” While these findings make it clear that rapid infant growth should be of significant interest to the public health community, the interpretation of the results of rapid infant growth studies is hindered by the fact that researchers have defined “rapid growth in infancy” in many different ways, and by the lack of studies using recent cohorts.

\textit{Rapid Growth in Infancy}

Researchers have chosen many different age intervals to represent “infancy” in studies of rapid growth. Age intervals have differed in both duration and timing. Sample age intervals include from birth to 8 days,\textsuperscript{17} birth to 1 month,\textsuperscript{18} birth to 4 months,\textsuperscript{17, 19, 20} birth to 6 months,\textsuperscript{21}
birth to 1 year,21-23 birth to 20 months,24 birth to 2 years,21, 23, 25, 26 6 months to 1 year, and 1 year to 2 years.21  Often, the rationale for selecting a particular age interval has not been systematic; some researchers performed secondary analyses of data sets and chose whatever age intervals were available,17, 19-22, 24 and in many other cases the selection of age intervals seemed arbitrary, as no rationale is given nor was any apparent reason obvious. The exception was a study by Toschke et al.,21 who analyzed several infant growth intervals using ROC curve analysis to determine which interval discriminated best between individuals who did or did not become overweight children.

Measures of “growth” have also been diverse. Absolute change, or the difference in a growth measure from the beginning to the ending of an age interval, has been most widely used. The absolute change in weight (g or kg),17, 18, 21-23 length (cm), BMI (kg/m²), ponderal index (kg/m³),21 weight-for-age z-score (SD),17, 20, 24-26 length-for-age z-score (SD),24, 25 and weight-for-length z-score (SD)24 have been studied. Weight-for-age, length-for-age, and weight-for-length percentiles (and their standardized z-scores) all correspond to sex- and age-specific reference data. CDC reference data, based on growth trends in the United States, were typically used with studies of American populations.17, 20 Reference data from the United Kingdom in 1990 were also commonly used.23, 25, 26 Rate of change, which estimates growth per unit of time from the beginning to the ending of an age interval, was less commonly measured.19

Certain growth measures may be preferable to others for use in infant growth studies. Toschke et al.,21 used ROC curve analysis to determine whether absolute gain in infant weight,
length, BMI, or ponderal index was the best predictor of childhood overweight. The analysis revealed that weight gain was a better predictor than all other tested measures, no matter what interval of infant growth was used. Z-score measures may be preferred in other cases because z-scores are standardized, meaning that they express the number of standard deviations an individual value is from the mean or median in a set of values. Thus, it is possible using z-scores to group or compare individuals of different sexes or ages in analyses. A final consideration in selecting infant growth measures for use in research is that measuring infants can be difficult; therefore, certain infant growth measures are more typically reliable than others. Weight measures, for example, can be obtained accurately if proper quality control is practiced, but length measures are more difficult to obtain accurately in a clinical setting. Therefore, length, length-for-age, weight-for-length, and ponderal index of infants can be considered less reliable.

“Rapid” infant growth has been characterized as both a continuous variable and a discrete variable. As a continuous variable, “rapid growth” is not explicitly defined. For example, Stettler et al., Monteiro et al., and Reilly et al. used absolute change in weight and weight-for-age z-score during infancy to calculate the relative risk of developing later obesity associated with each unit (g, kg, or SD) increase in growth. As a discrete variable, “rapid growth” is explicitly defined. For example, Monteiro et al., Reilly et al., Ong et al., and Cameron et al. defined rapid growth as an increase in weight-for-age z-score >0.67 SD during various infancy age intervals, which reflects the upward crossing of one centile line on standard growth curves, and Stettler et al. defined rapid growth as an increase in weight-for-age z-
score $\geq 1$SD between birth and 4 months, although no rationale was given for selecting this
cutoff. Toschke et al.\textsuperscript{21} defined rapid growth as an increase in weight $\geq 9764$ g between birth
and 2 years. This figure was chosen after ROC curve analysis determined that infant weight
gain from birth to 2 years was the best predictor of childhood overweight and that a weight
gain of 9764 g during that interval had the highest sensitivity and specificity.

The concept “rapid” growth may need to be re-examined. As described above, no clear
definition exists for the term. Additionally, rapid infant growth studies have often used data
from cohorts that were children at a time when the prevalence of childhood overweight and
obesity was much different than it is now. For example, studies have investigated rapid infant
growth in cohorts born in the early 1990’s,\textsuperscript{21, 23, 25} the 1980’s,\textsuperscript{22, 24} the 1960’s and 1970’s,\textsuperscript{11, 12, 17}
and even as long ago as 1959.\textsuperscript{19, 20} It is likely that a smaller threshold of infant growth now
predicts childhood overweight and obesity given their higher prevalence. Therefore, infant
growth may not need to be “rapid” to be “risky”.

\textit{Childhood Overweight and Obesity}

As with “infancy”, researchers have focused on many different time points to represent
“childhood” in their studies of the relationship between infant growth and childhood
overweight and obesity. Sample ages used to analyze the presence of childhood overweight
and obesity are 5 years,\textsuperscript{22, 25} 5 to 7 years,\textsuperscript{21} 7 years,\textsuperscript{19, 23} and 9 years.\textsuperscript{22, 26} As with the selection
of “infancy” age intervals, the choice to use a certain age to represent “childhood” is often
unstated or else dependent on the design of studies being used in secondary analyses; for
example, some studies used school entry\textsuperscript{21} or certain grades at school\textsuperscript{22} for the purpose of collecting childhood overweight and obesity data.

In rapid infant growth studies, “overweight” and “obesity” in childhood are most often defined as discrete variables using body mass index (BMI) cutoffs. Although BMI does not measure adiposity directly, it is considered a reasonable proxy for body fat\textsuperscript{1} using a child’s height and weight. Reilly \textit{et al.} \textsuperscript{23} defined obesity as an age- and sex-specific BMI \textgtreq 95\textsuperscript{th} percentile according to 1990 reference data from the UK. Although the current recommendation by the American Academy of Pediatrics (AAP) is to use the same cutoff with CDC reference data for American populations,\textsuperscript{1} Stettler \textit{et al.} \textsuperscript{19} used an older classification in which overweight was defined as an age- and sex-specific BMI \textgtreq 95\textsuperscript{th} percentile with reference to CDC growth curves. Other studies\textsuperscript{19,21,22} have defined overweight and obesity using sex- and age-specific BMI cutoff points based on adult cutoff points as described by the International Obesity Task Force (IOTF). Less often, continuous variables are used as measures of childhood overweight and obesity; for example, BMI,\textsuperscript{26} BMI z-score (SD),\textsuperscript{25} weight (kg),\textsuperscript{26} weight-for-age and height-for-age z-scores (SD),\textsuperscript{25} waist and hip circumference (cm),\textsuperscript{25,26} sum of skinfolds, specifically triceps, biceps, subscapular, suprailliac, thigh and calf skinfolds (mm),\textsuperscript{26} and total body fat (kg and \%)\textsuperscript{25,26} have all been used.

\textbf{Rapid Infant Growth Doesn’t Guarantee Childhood Overweight}

The relationship between rapid infant growth and childhood overweight and obesity is robust. It has been demonstrated by studies from around the world, using different intervals of infancy, infant growth measures, definitions of “rapid”, and childhood outcomes. Given this
evidence base, one could conclude that childhood overweight and obesity prevention efforts should focus on deterring rapid infant growth. This conclusion is sound; in a study by Toschke et al., infants without rapid weight gain had only a 4% chance of becoming overweight in childhood.

Yet, not every infant with rapid growth becomes an overweight or obese child. In the same study, the percent of rapidly growing infants that became overweight in childhood was only 19% even though rapidly growing infants were 5.7 times more likely to become overweight children. Researchers of childhood overweight and obesity should investigate this dichotomy. The findings of Toschke et al. suggest that there is a very strong relationship between rapid infant growth and childhood overweight for some children but not for others. The knowledge that some rapidly growing infants become overweight and obese children may be useful for guiding prevention efforts; pediatric medical providers monitor infant growth during well-baby appointments and could counsel parents about preventing excessive growth. However, understanding why other rapidly growing infants do not become overweight and obese children is equally important. Concerning all parents about the risks of excessive infant growth may not be appropriate, and may actually be detrimental, when only a subset of rapidly growing infants has a high risk of becoming overweight children. Characterizing the differences between rapidly growing infants that do and do not become overweight children could possibly result in the identification of factors protecting against childhood overweight that would allow for more precise prevention strategies.
Protective Factors Against Childhood Overweight and Obesity

Rapidly growing infants are similar in their amount of growth, but not necessarily in the quality of that growth. Every infant has a unique growth trajectory, yet perhaps growth trajectory patterns exist that are protective against childhood overweight and obesity. Determining area under the growth curve (AUC) is a possible way of investigating growth trajectory differences in infants.

AUC is a measure of the area between an infant’s growth curve and his or her baseline measure from birth. AUC provides information about an individual’s growth trajectory because it takes into account both the amount (y-axis) and timing (x-axis) of growth. Therefore two individuals with different growth trajectories over an interval would have different AUC values even if their absolute change in growth was the same. In general, individuals with accelerated growth early on in their growth curve would have higher AUC values than individuals with accelerated growth later in time. AUC has been used in studies of gestational weight gain but has yet to be used in rapid infant growth studies.

Other potentially protective factors could be identified by analyzing group differences between rapidly growing infants that do and do not become overweight and obese children. For example, groups could differ based on the characteristics of infants and their families; birth weight, birth order, gestational age, infant body composition changes, maternal and paternal BMI, and maternal gestational weight gain are examples of such differences. Demographic and environmental differences could include sex, race/ethnicity, socioeconomic status, locality (urban vs. rural), exposure to tobacco, exposure to television, and use of daycare. Parent
feeding behaviors, such as the duration and exclusivity of breastfeeding, nursing as opposed to bottle feeding, the use of formula, the timing of the introduction of solid foods, the kinds of solid foods introduced, and the frequency of feeding outside the home, might also vary between groups. Differences that are related to being non-overweight and obese in childhood when rapid infant growth occurs may be protective.

**Summary**

There were two aims of the current study. The first was to conduct a systematic analysis of infant growth intervals in order to determine which interval best discriminated between overweight and non-overweight children, and what amount of infant growth during that interval was the best predictor of subsequent childhood overweight. The second aim was to identify factors related to demographic characteristics, growth patterns, and feeding behaviors during infancy that might confer protective effects against the development of childhood overweight and obesity when risky infant growth occurs. The strengths and shortcomings of the studies summarized here have guided the research process.

The measure of infant “growth” used in the current study was absolute change in weight. This was chosen because infant weight measurements taken in a clinical setting are more accurate than infant recumbent length measurements, and because weight is a better predictor of childhood overweight than other infant growth measures. The interval defined as “infancy” was determined on the basis of ROC curve analysis as that with the largest area under the ROC curve. “Risky” growth was defined as weight gain equal to or greater than the criterion value; the criterion value is the amount of weight with the highest combined
sensitivity and specificity during the interval of infancy with the largest area under the ROC curve. The term “risky” infant growth was chosen in place of “rapid” infant growth because the amount of infant growth increasing risk of childhood overweight would not be considered “rapid” according to previous studies. Childhood overweight was defined, using current recommendations,¹ as an age- and sex-specific BMI ≥85th percentile, and the reference data used were from the CDC as this was an American population. The cohort studied is the most current to date, having been born in the year 2000 or later. Infants with risky growth were grouped based on their childhood overweight outcome and factors related to being non-overweight in childhood were identified as protective.
CHAPTER 2

JOURNAL MANUSCRIPT

Introduction

The prevalence of childhood overweight in the United States is a public health concern. The most recent data from the National Health and Nutrition Examination Survey revealed that a third of 6 to 11 year olds have a BMI at or above the 85th percentile according to the Centers for Disease Control and Prevention (CDC) distribution, and this cutoff has been recommended for use in assigning childhood overweight status. Overweight children are more likely than their normal-weight peers to have immediate and long-term health and psychosocial problems. Therefore, many researchers have examined early life risk factors for childhood overweight, including rapid infant growth.

The association between rapid infant growth and childhood overweight is robust. Positive associations are seen despite the use of diverse intervals of infancy, infant growth measures, definitions of “rapid growth”, and ages at which childhood overweight is measured. Yet, not every rapidly growing infant becomes an overweight child. Toschke et al. found that, while rapidly growing infants were 5.7 times more likely to become overweight children, only 19% actually became overweight in childhood.

This study had two objectives. The first was to conduct a systematic analysis of infant growth intervals in order to determine which interval best discriminated between overweight and non-overweight children, and what amount of infant growth during that interval was the
best predictor of subsequent childhood overweight. Second, we sought to identify factors during infancy that might confer protective effects against the development of childhood overweight when risky infant growth occurs. We considered demographic characteristics, growth patterns, and feeding choices in our analyses. In addition, we only used information available to pediatricians within the context of well-baby visits so that our findings can be understood within that context and any conclusions drawn from this study can be addressed within routine pediatric medical appointments.

**Methods**

**Participants**

This was a retrospective study of a cohort of children seen for routine well-baby and well-child pediatric appointments in central Pennsylvania. We extracted all data from medical records at a primary care pediatric office of a large academic medical hospital in 2008. The study was reviewed and approved by the Penn State College of Medicine Institutional Review Board in Hershey, PA.

We used the hospital’s computerized scheduling database to select medical records for data collection. The medical records of 239 patients met our inclusion criteria, which were: singleton children born in the year 2000 or later, and attendance at most routine well-baby visits (at 1 week and 1, 2, 4, 6, 9, 12, 15, 18 and 24 months of age) and at least one well-child visit between the ages of 6 and 8 years.
During the data collection process, we excluded patients from the subject pool if they were born pre- or post-term (gestational age <37 weeks or >42 weeks), if they had health problems that either required attention from the neonatal intensive care unit or that affected normal growth, and if their medical record did not actually have a well-child record at age 6, 7, or 8 years. This resulted in a final sample size of 192 subjects.

Data

For each subject, we obtained data from the post-delivery hospital discharge form, the family history record, each well-baby visit record, and the earliest well-child visit record between the ages of 6 and 8 years, as available. We collected the sex, birth date, gestational age, birth weight (recorded to the nearest gram), birth length (recorded to the nearest 0.5cm), parity, and parent education for each subject. In addition, we collected the visit date, weight (recorded to the nearest 0.01kg), length (recorded to the nearest 0.25cm), and descriptive information about parental feeding practices from every well-baby record, as well as the visit date, weight (recorded to the nearest 0.1kg), and height (recorded to the nearest 0.1cm) from the earliest well-child record from 6, 7, or 8 years, for each subject. Well-baby weight and length measurements were taken when infants were nude. Weight was measured using a digital scale, and recumbent length was marked on exam table paper as the crown to heel distance and measured using a measuring tape. At well-child visits, the weight and height of children were taken while they wore light clothing but no shoes using a digital scale with attached stadiometer.
**Childhood Overweight**

Childhood overweight was defined as a sex- and age-specific BMI $\geq 85^{th}$ percentile at age 6, 7, or 8 years according to the 2000 CDC distribution. We calculated childhood BMI percentiles for each subject using SAS version 9.2 (SAS Institute Inc., Cary, NC) and a SAS code available on the CDC website\textsuperscript{29} that requires the weight, height, sex, and actual age of each subject at their well-child visit for its calculations.

**Risky Infant Growth**

We used absolute change in weight as the measure of infant growth in our analyses as opposed to other measures of infant growth for two reasons. First, weight measures can be obtained accurately if proper quality control is practiced, but length measures are more difficult to obtain accurately in a clinical setting.\textsuperscript{27} Therefore, length and measures of infant growth using length (such as weight-for-length or ponderal index) may be considered less reliable than weight. In addition, other researchers have used receiver operating characteristic (ROC) curve analysis to assess gains in infant length, BMI, and ponderal index in addition to weight and found that, of these measures, infant weight change was the best predictor of childhood overweight.\textsuperscript{21}

ROC curve analysis can be used to assess the ability of screening measures to distinguish between individuals with and without an outcome. We used this function (MedCalc Version 9, MedCalc Software, Mariakerke, Belgium) to determine which interval of infant weight gain we would use for subsequent analyses. We systematically assessed the ability of infant weight gain
from 0 to 6 months, 6 to 12 months, 12 to 24 months, 0 to 12 months, and 0 to 24 months to discriminate between subjects who did and did not go on to become overweight children.

For each infant weight gain interval tested, a ROC curve was generated that plotted sensitivity (the true-positive rate) versus 100 – specificity (100 minus the true-negative rate, or, the false-positive rate) for the range of infant weight gain values. Then the area under the ROC curve was calculated. The area under the ROC curve was interpreted as the proportion of time that the infant weight gain of a randomly selected subject with childhood overweight exceeded that of a randomly selected subject without childhood overweight. Areas under the ROC curve potentially range from 0.5, which, in this study, would represent an infant weight gain interval that does not discriminate at all between subjects with and without childhood overweight, to 1.0, for an infant weight gain interval that completely discriminates between overweight and non-overweight children. In our study, the infant weight gain interval resulting in the largest area under the ROC curve was regarded as the most accurate for predicting childhood overweight and was used for subsequent analyses.

ROC curve analysis can also be used to identify the screening cutoff value associated with the smallest number of false positives and false negatives with respect to the outcome. In our study, the amount of weight gain during the selected interval of infancy resulting in the best combined sensitivity and specificity, the criterion value, was considered a threshold. Subjects were defined as at risk if they gained weight equal to or greater than the criterion value. At risk subjects that developed childhood overweight were defined as at risk/overweight, and at risk subjects that did not become overweight in childhood were defined
as at risk/resilient. We used the prevalence of overweight in the study cohort to determine the positive predictive value (the probability that an at risk infant becomes an overweight child), false-alarm rate (the probability that an at risk infant does not become an overweight child), and false-reassurance rate (the probability that a non-at risk infant becomes an overweight child).30

**Protective Factors**

We assessed differences in demographic characteristics, feeding behaviors, and growth patterns between at risk/overweight and at risk/resilient subjects to find possible explanations for their differential outcomes. Any factors significantly related to at risk/resilient group membership were considered *protective*. Significance for all tests was set at $p < 0.05$.

We used chi-square tests of independence to assess whether group membership was related to sex, parity (having a nulliparous, primiparous, or multiparous mother according to the post-delivery hospital discharge form), mother’s and father’s education (high school or less vs. more than high school), combined parent education (at least one parent with high school or less vs. both parents with more than high school, and both parents with less than high school vs. either parent with more than high school) and exclusively breastfeeding (feeding breast milk but not formula) for at least six months. We used independent samples t-tests to determine whether group mean differences existed for gestational age, birth weight, weight gain between successive well-baby visits, 0 to 24 month weight gain, area under the weight gain curve (AUC) in infancy, timing of the last report of breast milk, and timing of the first report of solid foods.
AUC has been used previously in studies of gestational weight gain\textsuperscript{28} and is used here as a measure of the area between an infant’s 0 to 24 month growth curve and his or her birth weight. We calculated AUC using the trapezoidal method. The height of each trapezoid, along the x-axis, is the number of days between two successive well-baby visit dates. The two bases of each trapezoid, along the y-axis, are the number of kilograms between the infant’s weight measures at those two well-baby visits and the infant’s birth weight baseline. Adding the areas of all trapezoids under the growth curve gives a figure that accounts for the amount and timing of infant weight gain. To put this into perspective, a kilogram gained in the first month adds about 700 kg-days to an infant’s AUC, but a kilogram gained in the 18\textsuperscript{th} month only adds about 200 kg-days. Therefore, different growth trajectories over an interval result in different AUC values even if the amount of weight gained during the interval is the same.

**Results**

The infant weight gain interval with the largest area under the ROC curve was 0 to 24 months (Table 1). As a screening measure, the proportion of time that 0 to 24 month weight gain distinguished between subjects with and without childhood overweight was 0.77 (95\% CI, 0.69-0.83). This was significantly better than the proportion attributable to random chance ($p = 0.0001$).

A total of 160 subjects, who had weight data at both 0 and 24 months, were included in the 0 to 24 month ROC curve analysis of infant weight gain. There were no significant differences in childhood BMI percentiles between subjects used in the ROC curve analyses and subjects excluded from the analyses because of missing data. The prevalence of childhood
overweight for subjects used in the 0 to 24 month ROC curve analysis was 26.3% (Table 2) at a mean age of 6.64 years (SD = 0.62).

The criterion value from 0 to 24 months was 8.57 kg (Table 1). This amount of weight gain had a sensitivity of 92.9% (95% CI, 80.5%-98.4%) and a specificity of 48.3% (95% CI, 39.0%-57.7%) (Table 3). There were 101 (63%) at risk subjects gaining ≥8.57 kg from 0 to 24 months. Of these, 39 were overweight in childhood (at risk/overweight) and 61 were not overweight in childhood (at risk/resilient) (Figure 1). In addition, there were 59 non-at risk subjects gaining <8.57 kg from birth to 24 months. Of these, 56 were not overweight in childhood and 3 were.

In this sample, the odds ratio of childhood overweight for at risk infants was 11.74, the positive predictive value was 39.0% (95% CI, 29.4%-49.3%), the false-alarm rate was 61% (95% CI, 50.7%-70.6%), and the false-reassurance rate was 5.0% (95% CI, 1.1%-13.9%) (Table 3).

At risk/resilient subjects had a lower mean 18 to 24 month weight gain (p = 0.04) and 0 to 24 month weight gain (p = 0.01) than at risk/overweight subjects (Table 4). The 18 to 24 month weight gain interval in at risk subjects was explored further. The area under the ROC curve was 0.62 (95% CI, 0.51-0.72). One outlier was identified, and removal of that data point resulted in a mean difference in 18 to 24 month weight gain (0.21 g [95% CI, -0.08 g -0.50 g]) was no longer significant (p = 0.08) between at risk/resilient and at risk/overweight subjects.

Mean gestational age, birth weight, AUC, and timing of the last report of breast milk did not differ between at risk/overweight and at risk/resilient subjects (Table 4). However, the timing of the first report of solid foods was later in at risk/resilient subjects than in at risk/overweight subjects (p = 0.01).
At risk/overweight and at risk/resilient group membership was not related to sex, parity, mother’s, father’s, or combined parent educational level (Table 5). However, being at risk/resilient was related to being exclusively breastfed for at least 6 months (p = 0.03).

**Comment**

Our systematic assessment of infant weight gain intervals using ROC curve analysis revealed that the period from 0 to 24 months and a weight gain of 8.57 kg or more during that interval best predicted subsequent childhood overweight. Among infants experiencing risky infant growth (≥ 8.57 kg from 0 to 24 months) 39% became overweight children, and 61% were resilient and did not develop childhood overweight. Feeding behaviors were found to be protective factors against childhood overweight. At risk/resilient subjects had a significantly later introduction to solid foods and were more likely to be exclusively breastfed for at least 6 months than subjects who were at risk/overweight.

We used ROC curve analysis to assess the efficacy of various infant weight gain intervals as screening measures for childhood overweight. This procedure replicated that of Toschke et al. in 2004. In our study sample, the weight gain interval from 0 to 24 months was the most accurate of those tested for predicting childhood overweight. The area under the ROC curve indicated that the 0 to 24 month weight gain of a subject with childhood overweight exceeded that of a subject without childhood overweight 77% of the time. A similar finding was made by Toschke et al., despite studying a German cohort with a much lower childhood overweight prevalence. This suggests that studying weight gain from birth to 2 years of age may consistently be more accurate than studying shorter intervals for the purpose of identifying
individuals whose infant weight gain increases their risk of childhood overweight. Longer intervals increase variability in the amount of weight gained between subjects, making differences in infant growth relating to subsequent overweight more apparent. In addition, longer intervals terminate at an age closer to that of the outcome measure than do shorter, earlier intervals, and it follows that differences between subjects identified at 24 months are more likely than those identified at 6 or 12 months to persist into childhood.

We used ROC curve analysis to identify the 0 to 24 month weight gain cutoff used to assign risk of childhood overweight. The criterion value for our sample was 8.57 kg, which pediatric medical providers may prefer to consider as roughly 19 lbs. The use of a criterion value for assigning risk was first used by Toschke et al. in 2004; his cutoff was 9.76 kg from 0 to 24 months. We chose to employ the same method as Toschke et al. because there is a lack of consensus among researchers about how to best identify infants at risk for subsequent overweight. Many researchers have defined “rapid infant growth” as an increase in weight-for-age z-score >+0.67 SD, which reflects the upward crossing of one centile line on standard growth curves. Others have used an increase in weight-for-age z-score >+1 SD as a threshold. Using a ROC curve-generated cutoff to screen for subsequent overweight has the benefit of systematically assessing every possible cutoff to determine the one that maximizes the number of true positive and true negative cases.

In a departure from previous research, we have chosen to label infant weight gain at or above our cutoff as “risky infant growth” instead of “rapid infant growth”. This is because a weight gain of 8.57 kg during infancy is less than the amount most researchers would identify
as “rapid”, yet infants gaining this amount of weight were 11.74 times more likely to become overweight children. Using a CDC growth curve, females born at the 10th, 50th, and 90th percentiles would be 24-month-olds at the 25th to 50th, 50th, and 50th to 75th percentiles, respectively, after 8.57 kg weight gain (see Appendix B). Likewise, males born at the 10th, 50th, and 90th percentiles would be 24-month-olds at the 10th to 25th, 25th to 50th, and 50th percentiles, respectively, after gaining 8.57 kg (see Appendix A). Upward centile line crossing rarely occurs with a weight gain of 8.57 kg. In fact, downward centile crossing occurs for individuals born at higher percentile ranges of birth weight. This finding suggests that the conclusions of rapid infant growth studies interpreting the infant weight gain of cohorts born several years ago may no longer be valid in light of the increasing prevalence of childhood overweight; infant growth may not need to be “rapid” to be “risky”. It also highlights the need for interpreting pediatric weight-for-age growth charts with caution; infants tracking along a percentile line may not be without risk for childhood overweight.

The criterion value of 8.57 kg weight gain from 0 to 24 months in our study sample was very sensitive. Nearly all (92.9%) overweight children were at risk infants. Therefore, there was a low false-reassurance rate; only 5% of infants who gained <8.57 kg became overweight children. The specificity of the criterion value was lower than the sensitivity. About half (48.3%) of non-overweight children were not at risk infants. Logically, the other half of non-overweight children were at risk infants. This was reflected in the false-alarm rate; 61% of infants who gained ≥8.57 kg did not become overweight children. These were at risk/resilient
subjects. The positive predictive value indicated that the remaining 39% of infants who gained \( \geq 8.57 \text{ kg} \) did become overweight children. These were the at risk/overweight subjects.

Our study is unique because we investigated why some individuals with risky infant growth become overweight children while others show resilience. Our sample size was small, and we had limited power to identify minute trends. Nevertheless, examination of demographic characteristic, growth pattern, and feeding behavior differences between at risk/resilient and at risk/overweight subjects revealed that certain feeding behaviors may be protective against childhood overweight, and our small sample size renders our findings clinically significant to pediatric medical providers.

The most clear protective factors against childhood overweight identified were feeding behaviors. The at risk/resilient group had a significantly later first report of solid foods than the at risk/overweight group. This supports the conclusion that a later introduction of solid foods is protective against childhood overweight. The timing of the last report of breast milk consumption was not significantly different between groups, but this variable does not take into consideration the supplementation of infant formula by the parents of some subjects. Feeding breast milk exclusively for at least 6 months was significantly related to being in the at risk/resilient group. This supports the conclusion that feeding breast milk in the absence of supplemental formula is also protective against childhood overweight.

Our non-significant findings raise questions for future research. Neither of the demographic characteristics we assessed was significantly different between groups. Sex and parent education (used as a stand-in for socioeconomic status [SES]) were unrelated to group
membership, even though 8.57 kg is proportionally more weight gain to a female infant than to a male infant, and even though there is a disproportionate burden of childhood overweight among lower SES groups. It would be interesting to learn whether being male is positively associated with being at risk/resilient in a larger sample. It would also be interesting to assess other measures of SES, such as household income, as it is possible that parent education poorly represents SES in this community.

Similarly, no protective factors against childhood overweight were identified from assessments of infant growth patterns. At risk/resilient subjects did gain significantly less weight from 0 to 24 months than did at risk/overweight subjects, however our analyses didn’t reveal any clear factors influencing this weight gain difference. Most likely, the difference is the result of greater weight gain in the at risk/overweight group cumulatively across infancy, as the mean weight gain of at risk/overweight subjects exceeded that of at risk/resilient subjects during every interval between successive well-baby visits (see Appendix C). None of these intervals had significant mean weight gain differences between groups (once the outlier influencing 18 to 24 month mean weight gain difference was removed) however the persistence of the trend across two years may be meaningful. There were no significant differences in birth weight or gestational age between groups. Therefore, we cannot conclude that babies who are born smaller and gain ≥8.57 kg during infancy are more protected from childhood overweight than babies who are larger at birth and gain a similar amount of infant weight. Parity was also not related to group membership, even though birth order has been
shown to be related to size at birth and growth velocity.\textsuperscript{32} There was no significant difference in AUC between groups, which means that no group-specific growth trajectories were found.

In conclusion, the criterion value of 8.57 kg (roughly 19 lbs) weight gain from birth to 2 years in our study sample was a useful screening tool for assessing risk of childhood overweight at age 6 to 8 years. The prevalence of childhood overweight in the study sample was 26.25%, yet this figure dropped to 5% for non-at risk infants gaining <8.57 kg and increased to 39% in at risk infants gaining ≥8.57 kg. The variables identified as protective factors for at risk infants are clinically relevant; pediatric medical providers can, and are recommended to,\textsuperscript{1} counsel families about infant feeding choices, such as initiating and maintaining exclusive breastfeeding for 6 months until the introduction of appropriate solid foods.

The results of this study may have been affected by selection bias because we have assessed a sample of individuals who attend regular pediatric appointments; it is possible that the results are not, therefore, generalizable to the entire population or to other populations. Yet, they provide insight that protective factors may exist and confer resilience even when risky infant growth occurs; this warrants further exploration in larger, more diverse, and more controlled studies of recent cohorts.
**Table 1. Area under the Receiver Operating Characteristic (ROC) Curve, Criterion Value, Sensitivity and Specificity for Infant Weight Gain Intervals.**

<table>
<thead>
<tr>
<th>Infant Weight Gain Interval, months</th>
<th>Number of Subjects Used in Analysis</th>
<th>Criterion Value, kg</th>
<th>Sensitivity*</th>
<th>Specificity*</th>
<th>Area Under the ROC Curve*</th>
<th>P-Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6</td>
<td>169</td>
<td>4.78</td>
<td>50.0</td>
<td>78.1</td>
<td>0.66</td>
<td>0.0016</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(34.9-65.1)</td>
<td>(69.7-85.0)</td>
<td>(0.58-0.73)</td>
<td></td>
</tr>
<tr>
<td>6-12</td>
<td>165</td>
<td>2.30</td>
<td>38.6</td>
<td>81.8</td>
<td>0.62</td>
<td>0.0217</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(24.4-54.5)</td>
<td>(73.8-88.2)</td>
<td>(0.54-0.69)</td>
<td></td>
</tr>
<tr>
<td>12-24</td>
<td>157</td>
<td>2.98</td>
<td>67.5</td>
<td>64.1</td>
<td>0.69</td>
<td>0.0003</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(50.9-81.4)</td>
<td>(54.7-72.8)</td>
<td>(0.61-0.76)</td>
<td></td>
</tr>
<tr>
<td>0-12</td>
<td>165</td>
<td>6.34</td>
<td>67.4</td>
<td>64.8</td>
<td>0.68</td>
<td>0.0002</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(51.5-80.9)</td>
<td>(55.6-73.2)</td>
<td>(0.61-0.75)</td>
<td></td>
</tr>
<tr>
<td>0-24</td>
<td>160</td>
<td>8.57</td>
<td>92.9</td>
<td>48.3</td>
<td>0.77</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(80.5-98.4)</td>
<td>(39.0-57.7)</td>
<td>(0.69-0.83)</td>
<td></td>
</tr>
</tbody>
</table>

*Data are given as value (95% confidence interval).
†Probability that the Area Under the ROC Curve is significantly different from 0.50.
Figure 1. Weight Gain from 0 to 24 Months in Subjects With and Without Childhood Overweight
Table 2. Characteristics of the Subjects Included in the 0 to 24 Month ROC Curve Analysis

<table>
<thead>
<tr>
<th>Variables</th>
<th>Number of Observations</th>
<th>Mean or Proportion*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (% Female)</td>
<td>160</td>
<td>51.3</td>
</tr>
<tr>
<td>Birth Weight (kg)</td>
<td>160</td>
<td>3.52 (0.45)</td>
</tr>
<tr>
<td>Gestational Age (wk)</td>
<td>129</td>
<td>39.46 (1.22)</td>
</tr>
<tr>
<td>Parity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nulliparous (%)</td>
<td></td>
<td>40.6</td>
</tr>
<tr>
<td>Primiparous (%)</td>
<td></td>
<td>36.3</td>
</tr>
<tr>
<td>Biparous or Multiparous (%)</td>
<td></td>
<td>17.5</td>
</tr>
<tr>
<td>0 to 24 Month Weight Gain (kg)</td>
<td>160</td>
<td>9.17 (1.41)</td>
</tr>
<tr>
<td>Age at Well-Child Visit (yr)</td>
<td>160</td>
<td>6.64 (0.62)</td>
</tr>
<tr>
<td>Childhood BMI Percentile</td>
<td>160</td>
<td>62.77 (26.35)</td>
</tr>
<tr>
<td>Childhood Weight Status (% Overweight)</td>
<td>160</td>
<td>26.3</td>
</tr>
<tr>
<td>Combined Parent Education</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td>Both Parents More Than High School (%)</td>
<td></td>
<td>38.8</td>
</tr>
<tr>
<td>At Least One Parent More Than High School (%)</td>
<td></td>
<td>53.1</td>
</tr>
<tr>
<td>Neither Parent More Than High School (%)</td>
<td></td>
<td>25.6</td>
</tr>
<tr>
<td>Feeding Behaviors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exclusively Breastfed At Least 6 Months (% Yes)</td>
<td>135</td>
<td>27.5</td>
</tr>
<tr>
<td>First Report of Solid Foods (mo)</td>
<td>145</td>
<td>5.97 (2.50)</td>
</tr>
<tr>
<td>Last Report of Breast Milk (mo)</td>
<td>135</td>
<td>4.23 (5.34)</td>
</tr>
<tr>
<td>AUC (kg-days)</td>
<td>160</td>
<td>4483.45 (861.43)</td>
</tr>
</tbody>
</table>

*Proportion data are given as value (standard deviation).
Table 3. Diagnostic Interpretations using the Criterion Value to test for Childhood Overweight.

<table>
<thead>
<tr>
<th>Diagnostic Measure</th>
<th>Result*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity or True-Positive Rate</td>
<td>92.9% (80.5%-98.4%)</td>
</tr>
<tr>
<td>Specificity or True-Negative Rate</td>
<td>48.3% (39.0%-57.7%)</td>
</tr>
<tr>
<td>False-Positive Rate</td>
<td>52.7% (42.3%-61.0%)</td>
</tr>
<tr>
<td>False-Negative Rate</td>
<td>7.1% (1.6%-19.5)</td>
</tr>
<tr>
<td>Positive Predictive Value</td>
<td>39.0% (29.4%-49.3%)</td>
</tr>
<tr>
<td>Negative Predictive Value</td>
<td>95.0% (86.1%-98.9%)</td>
</tr>
<tr>
<td>False-Alarm Rate</td>
<td>61.0% (50.7%-70.6%)</td>
</tr>
<tr>
<td>False-Reassurance Rate</td>
<td>5.0% (1.1%-13.9%)</td>
</tr>
<tr>
<td>Positive Likelihood Ratio</td>
<td>1.80 (1.5-2.2)</td>
</tr>
<tr>
<td>Negative Likelihood Ratio</td>
<td>0.15 (0.05-0.4)</td>
</tr>
</tbody>
</table>

*Data are given as value (95% confidence interval).
### Table 4. Mean Differences between At Risk/Overweight and At Risk/Resilient Subjects

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean Difference*</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth Weight, kg</td>
<td>0.08 (-0.10 - 0.26)</td>
<td>p = 0.20</td>
</tr>
<tr>
<td>Weight Change, kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birth to 1 Week</td>
<td>0.001 (-0.06 - 0.06)</td>
<td>p = 0.49</td>
</tr>
<tr>
<td>1 Week to 1 Month</td>
<td>0.03 (-0.14 - 0.19)</td>
<td>p = 0.38</td>
</tr>
<tr>
<td>1 to 2 Months</td>
<td>0.03 (-0.15 - 0.21)</td>
<td>p = 0.37</td>
</tr>
<tr>
<td>2 to 4 Months</td>
<td>0.05 (-0.11 - 0.22)</td>
<td>p = 0.26</td>
</tr>
<tr>
<td>4 to 6 Months</td>
<td>0.09 (-0.06 - 0.25)</td>
<td>p = 0.12</td>
</tr>
<tr>
<td>6 to 9 Months</td>
<td>0.08 (-0.12 - 0.28)</td>
<td>p = 0.21</td>
</tr>
<tr>
<td>9 to 12 Months</td>
<td>0.04 (-0.15 - 0.23)</td>
<td>p = 0.33</td>
</tr>
<tr>
<td>12 to 15 Months</td>
<td>-0.03 (-0.20 - 0.14)</td>
<td>p = 0.38</td>
</tr>
<tr>
<td>15 to 18 Months</td>
<td>0.04 (-0.19 - 0.27)</td>
<td>p = 0.36</td>
</tr>
<tr>
<td>18 to 24 Months</td>
<td>0.28 (-0.02 - 0.59)</td>
<td>p = 0.04</td>
</tr>
<tr>
<td>0 to 24 Months</td>
<td>0.47 (0.05 - 0.88)</td>
<td>p = 0.01</td>
</tr>
<tr>
<td>AUC, kg-days</td>
<td>101.61 (-195.15 – 398.37)</td>
<td>p = 0.25</td>
</tr>
<tr>
<td>Gestational Age, weeks</td>
<td>0.45 (-0.12 – 1.03)</td>
<td>p = 0.06</td>
</tr>
<tr>
<td>Timing of Last Report of Breast Milk, months</td>
<td>-1.53 (-3.65 - .60)</td>
<td>p = 0.08</td>
</tr>
<tr>
<td>Timing of First Report of Solid Foods, months</td>
<td>-1.28 (-2.33 - -.022)</td>
<td>p = 0.01</td>
</tr>
</tbody>
</table>

*Data are given as value (95% confidence interval).
<table>
<thead>
<tr>
<th>Measure</th>
<th>At Risk/Overweight, n</th>
<th>At Risk/Resilient, n</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>17</td>
<td>36</td>
<td>p = 0.16</td>
</tr>
<tr>
<td>Female</td>
<td>22</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Parity</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Nulliparous</td>
<td>15</td>
<td>25</td>
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</tr>
<tr>
<td>Primiparous</td>
<td>14</td>
<td>23</td>
<td>p = 0.96</td>
</tr>
<tr>
<td>Multiparous</td>
<td>7</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Mother’s Education</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>High School or Less</td>
<td>15</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>More than High School</td>
<td>18</td>
<td>32</td>
<td>p = 0.33</td>
</tr>
<tr>
<td>Father’s Education</td>
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<td></td>
</tr>
<tr>
<td>High School or Less</td>
<td>13</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>More than High School</td>
<td>15</td>
<td>27</td>
<td>p = 0.37</td>
</tr>
<tr>
<td>Combined Parent Education</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At Least One Parent High School or Less</td>
<td>16</td>
<td>20</td>
<td>p = 0.45</td>
</tr>
<tr>
<td>Both Parents More than High School</td>
<td>14</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Both Parents High School or Less</td>
<td>11</td>
<td>12</td>
<td>p = 0.33</td>
</tr>
<tr>
<td>At Least One Parent More than High School</td>
<td>19</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Exclusively Breastfed for At Least 6 Months</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>5</td>
<td>20</td>
<td>p = 0.03</td>
</tr>
<tr>
<td>No</td>
<td>33</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 3

CONCLUSIONS

Infancy is a time of incredible change. It is associated with the greatest increase in size outside of the womb, and huge transitions in feeding also occur.\textsuperscript{33} It is not surprising, therefore, that variations in infant growth and infant feeding have lasting outcomes. In the case of this study, infant weight gain of 8.57kg or more greatly increases the risk for childhood overweight (OR = 11.74), while adhering to public health-recommended infant feeding practices protect against childhood overweight. The findings of this study have interrelated significance to medical and research communities, and bring to the forefront the need for further research to confirm, clarify, and extend the knowledge that has been learned here.

Significance to Pediatric Medical Providers

Monitoring growth in infants is a central function of well-baby visits. Normal growth is an indicator of health. Historically, the connotation of “normal” growth has been “adequate” growth, as weight checks were used to screen for failure to thrive. That nuance is still understood by parents, who often regard weight checks as progress reports on the success of their parenting. Yet, the growth of many infants is now more than adequate, and one could conclude from infant growth studies that it may be important to use weight checks to look for risky infant growth. But what is risky infant growth?

One of the most interesting findings of this study was the amount of infant weight gain increasing the risk for childhood overweight. According to Cole,\textsuperscript{34} “it is assumed that a child
growing ‘normally’ stays on the same centile over time, a pattern called tracking. Conversely, when children grow faster or slower than average, their weight centile changes over time, a pattern known as centile crossing.” Yet, the amount of weight gain identified by the current study as “risky” would rarely result in upward centile crossing, and would even result in downward centile crossing for some infants. How, then, can providers distinguish between normal growth and risky growth? Has “normal” growth shifted? The answer is that this is likely an artifact of the increasing prevalence of childhood overweight, and more studies assessing the relationship between infant weight gain and childhood overweight must be done with recent cohorts to confirm or refute these findings.

Perhaps it would be better to focus on feeding behaviors during infancy rather than on infant growth. 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.”\(^1\) The World Health Organization also recommends exclusive breastfeeding until 6 months, at which time the introduction of complimentary foods is recommended.\(^35\) Although these are the recommendations, they are not the norms. Data from the Feeding Infants and Toddlers Study indicate that only 40% of 4- to 6-month-olds consumed breast milk at least once per day, and that this amount decreased to 14% in 12- to 14-month-olds.\(^33\) In addition, solid foods were introduced before 6 months of age to 94% of infants. Pediatric medical providers are excellent candidates for helping to change infant feeding norms. Many parents have regular contact with their child’s provider through the context of well-baby medical visits, and regard their child’s provider as an authority on child
health. Providers are recommended to use these opportunities to serve as “counselors in obesity prevention”\(^1\) and to target their prevention efforts on all children from birth.

To that end, it may be preferable for providers to focus on healthy infant feeding behaviors as outcomes, as these are known to correlate with appropriate growth outcomes in infancy and, according to this study, protect against childhood overweight even if risky infant growth occurs. The current focus on weight as an outcome may negatively influence parents and deter them from choosing appropriate child feeding behaviors; a parent may choose to feed their infant in a particular way in order to achieve a certain weight outcome. Dewey summarizes this concept very well: “healthcare providers must be trained not to overemphasize weight gain as the main indicator of adequate growth and development, and to include other indicators such as motor development. Assuring caregivers that an infant is thriving, rather than congratulating them on how much weight the child has gained, may help to change attitudes that ‘bigger is better’ during infancy.”\(^{36}\)

**Significance to the Childhood Obesity Research Community**

The childhood obesity research community could serve the medical community by studying how to best counsel parents about appropriate infant feeding behaviors to influence positive outcomes. Such research could form the basis of continuing medical education, which the Expert Committee states is often lacking from health care education.\(^1\)

Childhood obesity researchers should also re-examine the concept “rapid infant growth” with recent cohorts, as the current study found that infant growth does not have to be “rapid”
in order to be “risky”. In addition, in order to support or refute the findings of the study presented here, more studies should be conducted using our procedure. Future studies including ethnically/racially diverse populations from varied localities would add to the evidence base, as the sample for the current study was likely to be largely Caucasian and rural (although these variables could not be assessed). Prospective studies would be ideal for two reasons. First, a prospective study could include a very recent cohort. Second, a prospective study could be designed so that data not present in pediatric medical records could also be collected and assessed. It would be interesting to investigate at risk/resilient and at risk/overweight group differences with respect to variables such as infant body composition changes, maternal and paternal BMI, maternal gestational weight gain, race/ethnicity, family income, exposure to tobacco, exposure to television, use of daycare, frequency of feeding outside the home, quality of solid foods consumed, use of bottles vs. breast for delivering breast milk, formula consumption, amount of sleep, and parent perception of infant soothability. Further, using cluster analysis or growth mixture modeling to identify infant weight gain trajectories associated with resilience would supplement the findings of the current study.
APPENDIX A

Male Weight Gain of 8.57 kg from 0 to 24 Months on a CDC Growth Curve

Birth to 36 months: Boys
Length-for-age and Weight-for-age percentiles

- Birth weight at the 90th percentile
- Birth weight at the 50th percentile
- Birth weight at the 10th percentile
APPENDIX B

Female Weight Gain of 8.57 kg from 0 to 24 Months on a CDC Growth Curve

Birth to 36 months: Girls
Length-for-age and Weight-for-age percentiles

Birth weight at the 90th percentile
Birth weight at the 50th percentile
Birth weight at the 10th percentile
APPENDIX C

0 to 24 Month Mean Weight Gain in At Risk/Overweight and At Risk/Resilient Subjects
Appendix D

Weight Gain During Infant Age Intervals in Subjects With and Without Childhood Overweight

Weight Gain from 0 to 6 Months in Subjects With and Without Childhood Overweight

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Criterion Value
Weight Gain from 6 to 12 Months in Subjects With and Without Childhood Overweight

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Weight Gain from 12 to 24 Months in Subjects With and Without Childhood Overweight

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Criterion Value
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REFERENCES


