Chapter 2
Epidemiology of the Metabolic Syndrome in Youth: A Population-to-Clinical-Based Perspective

Sarah E. Messiah, Kristopher L. Arheart, and James D. Wilkinson

Abstract Recent studies have reported an association between childhood obesity and the development of a cluster of cardiometabolic disease risk factors characterized by variable combinations of insulin resistance, dyslipidemia, and hypertension, which some have termed metabolic syndrome. In turn, this clustering is associated with the onset of type 2 diabetes and long-term atherosclerotic cardiovascular complications in both childhood and adulthood. In this chapter, we summarize the national prevalence estimates for metabolic syndrome in US youth based on various definitions that employ either a clinical threshold value for each component or a percentile threshold based on some combination of age, sex, and ethnicity. The national estimates are followed by a summary of large, key regional studies. The authors are aware that literally hundreds of small national and international clinical studies have estimated the prevalence of metabolic syndrome in youth, and summarizing them all is beyond the scope of this chapter.

Keywords Epidemiology • Childhood obesity • Metabolic syndrome • Pediatric • Adolescent

S.E. Messiah, Ph.D., MPH (✉)
Division of Pediatric Clinical Research, Department of Pediatrics,
University of Miami Miller School of Medicine, Batchelor Children's Research Institute #541,
1580 NW 10th Avenue, Miami, FL 33130, USA
e-mail: smessiah@med.miami.edu

K.L. Arheart, B.S., M.S., EdD
Division of Biostatistics, Department of Epidemiology
and Public Health, University of Miami Miller School of Medicine,
Miami, FL, USA

J.D. Wilkinson, M.D., MPH
Division of Pediatric Clinical Research, Department of Pediatrics,
Leonard M. Miller School of Medicine,
Miami, FL, USA

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Introduction

Not too long ago, the terms "metabolic syndrome" and "child" would not have been mentioned in the same sentence. However, an entirely different scenario is rapidly unfolding before our society and our health-care system. Deeply rooted in the current childhood obesity epidemic are both the components of metabolic syndrome (elevated blood pressure and glucose levels, hypertriglyceridemia, low HDL cholesterol levels, and central adiposity) and the syndrome itself (three or more of these components in the same individual). Children are being diagnosed with metabolic syndrome at increasingly younger ages, including some as young as 8 years old [1]. The longer-term consequences of childhood obesity and its metabolic changes are now just starting to emerge [2–4].

Childhood overweight is a major public health problem. Virtually no age group is left unscathed; currently one in four US children *under the age of 5* is overweight [5] (Fig. 2.1). Even more alarming is the fact that the latest US pediatric obesity prevalence estimates for all children ages 2–18 for the first time now included levels of *morbid obesity* (a body mass index percentile for age and sex at or above the 97th percentile), whereas previous reports only included up to the 95th percentile (cutoff for obese) [5]. However, the latest news is that morbidity associated with childhood obesity is occurring at younger ages and is associated with adult diseases, including adult-onset obesity [3], atherosclerotic cardiovascular disease, and diabetes [7–10]. Autopsy results from the Pathobiological Determinants of Atherosclerosis in Youth (PDAY) study and the Bogalusa Heart Study have revealed that the atherosclerotic process begins in childhood, for example [8, 11–14].

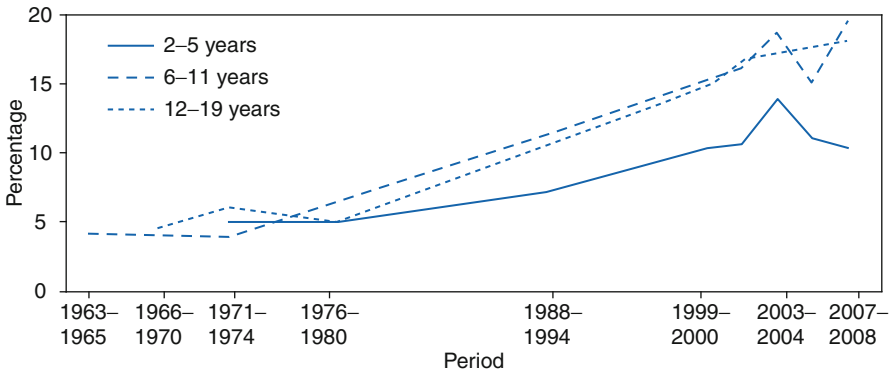

Fig. 2.1 Prevalence of obesity among children and adolescents, by age group, United States, 1963–2008 (Reprinted from Centers for Disease Control and Prevention [6])

Pathophysiology of the Metabolic Syndrome

The concept of metabolic syndrome in childhood can easily diverge into two different and, at times, opposing views. Epidemiologically, the literature indicates quite clearly that this cluster of abnormal risk factors exists in both clinic and population-based samples and is highly prevalent in the obese. However, the pathophysiological view suggests that this association is not so clear. For example, some have questioned the advantage of naming a syndrome that includes several different components. Instead, should each individual risk factor be treated independently? On the other hand, should a different set of criteria be based on racial-ethnic background? The literature consistently shows that certain ethnic groups display elevated risk factors at baseline. Among those children who are overweight or obese, insulin resistance is likely more important than overall adiposity in the development of the syndrome. Therefore, the accumulation of visceral fat, as opposed to subcutaneous abdominal fat, or alternatively, increased ectopic fat, may be important in the pathophysiology of the disorder. For example, Cruz and colleagues [15] report that visceral fat, in addition to total fat, is an important contributor to differences in insulin sensitivity among overweight Hispanic youth with a family history of type 2 diabetes.

Although a consensus has been reached in defining metabolic syndrome in adults [16], controversy nevertheless remains concerning the actual underlying causal factors. Currently, the most accepted hypothesis supported by prospective studies is that obesity and insulin resistance are the key underlying factors in the syndrome [17, 18], and both have been explored in children using both cross-sectional and prospective studies [15, 19] (Fig. 2.2).

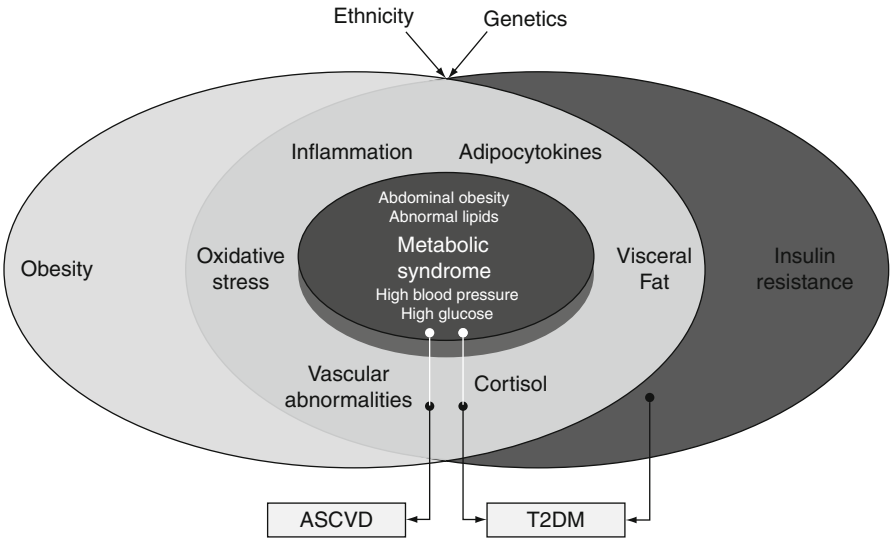

Fig. 2.2 Schematic of components of the metabolic syndrome (Reprinted from Steinberger et al. [16]. With permission from Lippincott Williams & Wilkins)

Controversy Surrounding a Universal Definition

Identifying children who are at risk for metabolic syndrome has remained elusive and as stated above, controversial as well. Because it is a recently emerged syndrome, its validity and purport have been questioned by organizations such as the Federal Drug Administration (FDA) and the American Diabetes Association (ADA) [20]. The most widely accepted opinion is stated in the International Diabetes Federation's (IDF) Joint Interim consensus report, which affirms that all components together are important for risk prediction [21] and that early diagnosis promotes preventative measures [22].

Much of the controversy surrounding the syndrome in children is its definition. Definitions of pathological processes are typically based on endpoints. The difficulty in defining these cardiovascular risk factors in childhood is that most children have not reached the endpoint (atherosclerotic cardiovascular disease) [23–25]. Thus, there is technically no single, widely accepted operational definition of metabolic syndrome in children. This confusion has led to more than 50 different definitions being proposed in the pediatric literature, with the American Heart Association and International Diabetes Federation definitions being used most prominently in the literature.

Many of the pediatric metabolic syndrome definitions are based on a modified adult definition [26] proposed by Cook et al. [25] and include the following components in variation: (1) waist circumference greater than the 90th percentile for age, sex, and ethnicity; (2) a fasting glucose level greater than 100 mg/dL; (3) a blood pressure (systolic or diastolic) greater than the 90th percentile for age and height; (4) fasting triglyceride levels greater than 110 mg/dL; and (5) HDL cholesterol less than 40 mg/dL (Table 2.1). More recently, attention has been paid to the definition published by the IDF in 2007. The report was compiled in Australia by a group of international doctors intending to create a "universally accepted diagnostic tool that is easy to use in clinical practice and that does not rely upon measurement only available in research settings" [22]. Adolescent metabolic syndrome defined by the IDF states that those below ten cannot be diagnosed, those aged 10–16 have specific thresholds for each of the components proposed by Cook, and those above 16 should be diagnosed with same criteria as adults.

The challenge in pediatrics lies in the difficulty of arriving at an appropriate threshold for each risk factor that takes into account age and sex as well as continuous growth, the onset of puberty, and perhaps ethnic background. This challenge has led several groups, including ours [1], to employ percentiles adjusted for age and sex. This approach then raises the issue of what percentile maximizes both sensitivity and specificity and what historical cohort is used to derive these thresholds: one before the current obesity epidemic, perhaps as far back as NHANES I or II, or one that is current and potentially skewed toward higher values?

Table 2.1 Various definitions of metabolic syndrome for children and adolescents

	Cook et al. [25]	De Ferranti et al. [27]	Cruz et al. [15]	Weiss et al. [28]	IDF[b] [22]
Obesity	WC ≥90th percentile (age- and sex-specific, NHANES III)	WC >75th percentile	WC ≥90th percentile (age-, sex-, and race-specific, NHANES III)	BMI –Z score ≥2.0 (age- and sex-specific)	≥90th percentile or adult cut-off if lower
HDL-C	≤40 mg/dL (all ages/sexes, NCEP)	<1.3 mmol/L (<50 mg/dL)	≤10th percentile (age- and sex-specific, NHANES III)	<5th percentile (age-, sex- and race-specific, NGHS)	<1.03 mmol/L (<40 mg/dL)
Blood pressure	≥90th percentile (age-, sex-, and height-specific, NHBPEP)	>90th percentile	>90th percentile (age- and sex-specific, NHANES III)	>95th percentile (age-, sex-, and height-specific, NGHS)	Systolic ≥130, diastolic ≥85 mmHg
Triglycerides	≥110 mg/dL (age-specific, NCEP)	≥1.1 mmol/L (≥100 mg/dL)	≥90th percentile (age-, sex-, and race-specific, NHANES III)	>95th percentile (age-, sex-, and race-specific, NGHS)	≥1.7 mmol/L (≥150 mg/dL)
Glucose	≥110 mg/dL	≥6.1 mmol/L (≥110 mg/dL)	Impaired glucose tolerance (ADA criterion)	Impaired glucose tolerance (ADA criterion)	≥5.6 mmol/L (100 mg/dL)

[a]AHA definition applies to ages 12–19

[b]IDF definition applies only to those aged 10–16; those younger cannot be diagnosed and those older use adult criteria

Ethnicity and the Prevalence of Metabolic Syndrome

The prevalence of obesity remains high among all age and ethnic groups in the USA. However, the prevalence of obesity among African-Americans and Hispanic and Mexican Americans is rising disproportionately (Fig. 2.3). Analysis of NHANES III found that the prevalence of metabolic syndrome varies more specifically between ethnic groups in the USA. The rate was highest among Hispanic (6–13%) and lowest among black adolescents (2–3%), with white adolescents in between 5% to 11% [25, 27]. Smaller clinical studies have estimated the prevalence to be between 4% and 9% in preadolescents and adolescents and also reported higher prevalence rates in minorities than in whites [15, 29, 30].

Few of these studies examined differences in prevalence of MS by race and ethnicity in children younger than 12 however. Although rates of overweight and obesity may vary by ethnicity, it is currently unclear if obesity alone is driving these differences in MS components. If individual MS components vary by ethnic group and are independent of obesity, then these findings could, in turn, be used to target prevention and treatment programs. Collectively, the authors of these studies concluded that the higher prevalence among Hispanic youth can most likely be attributed to their overall higher rates of overweight and obesity. Similarly, studies among US adults have reported that the prevalence of metabolic syndrome is higher among Hispanics (31.9%) and lower among black adults (21.6%) than among white adults (23.8%) [31].

Paradoxically, although the prevalence of obesity among black and non-Hispanic black adolescents in the USA is also high (21%), they tend to have a lower prevalence of the syndrome [25, 32, 33] when a definition similar to that used by the NCEP Adult Treatment Panel III is applied. Some have hypothesized that this paradox may result from the fact that black youth (like adults) have lower triglycerides and higher HDL cholesterol levels than do their white counterparts, even though they have higher blood pressure [32]. These findings suggest that the impact of obesity on the components of metabolic syndrome may vary by ethnic group. Indeed, a recent

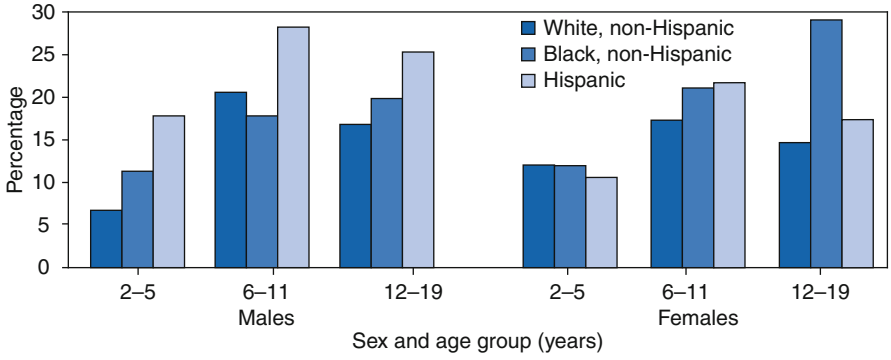

Fig. 2.3 Prevalence of obesity among children and adolescents by sex, age group, and race/ethnicity, United States, 2007–2008 (Reprinted from Centers for Disease Control and Prevention [6])

American Heart Association scientific statement calls for research to determine whether there are racial and ethnic differences in the overall prevalence, mechanisms, and pathways to metabolic syndrome in children and adolescents [16].

Relationship Between Socioeconomic Status and Pediatric Metabolic Syndrome

Limited research has resulted in conflicting views on the association between socioeconomic status and adolescent metabolic syndrome. Initially, childhood overweight, and thus the metabolic syndrome, was considered an issue most heavily concentrated in high-income populations; however, in 2010, over 80% of obese children under 5 were living in developing countries [34] (Fig. 2.4).

One analysis of NHANES 1999–2002 found no correlation between the two [36]. On the other hand, several studies have found an inverse relationship between adolescent SES and adulthood metabolic syndrome in women, even independent of

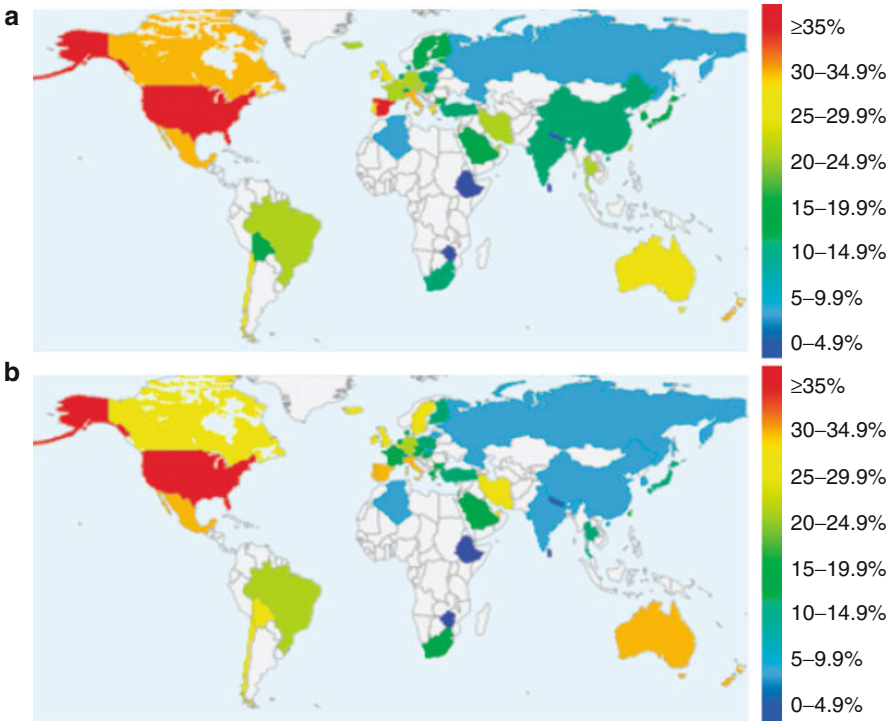

Fig. 2.4 Percent of overweight (**a**) female and (**b**) male children by country (Reprinted from Spruijt-Metz [35]. With permission from John Wiley & Sons, Inc.)

adolescent BMI and blood pressure levels [37]. Women from the lowest childhood social classes are at over twice the risk of having low HDL cholesterol and high waist circumference than from the highest social classes [38]. One reason for this difference is that the social pressure against obesity is stronger amongst those with higher socioeconomic positions, a trend that continues through adolescents [39]. A study of female adolescents in England found that adolescents with a higher SES were more aware of social ideals of "slimness" and used a lower body mass index to define "fat" [40]. Additional tests could reveal that such factors indeed demonstrate an association between SES and pediatric metabolic syndrome.

Another social indicator showing a correlation with adult metabolic syndrome is food security. A study conducted by Parker using data from the NHANES Surveys 1999–2006 found that households with low food security are also more likely to have adults with metabolic syndrome [41]. Interestingly, this same study did not observe an association between pediatric metabolic syndrome and food security. Various reasons were cited, such as potential nutritious food sources at school or parents sacrificing their healthier food for the children.

Population-Based Prevalence Estimates of Pediatric Metabolic Syndrome

The National Health and Nutrition Examination Survey (NHANES) is the primary data source for monitoring the prevalence of overweight and obesity in the USA, as well as all components of metabolic syndrome in those aged 12 and older. Also, since 1960, NHANES anthropometry data has been used to determine obesity levels in the USA [42]. NHANES surveys used a stratified, multistage probability design to capture a representative sample of the civilian non-institutionalized US population. The major objectives of NHANES are: (1) to estimate the number and percent of persons in the US population and designated subgroups with selected diseases and risk factors; (2) to monitor trends in the prevalence, awareness, treatment, and control of selected diseases; (3) to monitor trends in risk behaviors and environmental exposures; (4) to analyze risk factors for selected diseases; (5) to study the relationship between diet, nutrition and health; (6) to explore emerging public health issues and new technologies; (7) to establish a national probability sample of genetic material for future genetic research; and (8) to establish and maintain a national probability sample of baseline information on health and nutritional status.

Although the NHANES III (1988–1994) survey was designed to be nationally representative for either 3 or 6 years of data collection, since 1999 the survey has been conducted bi-annually and since 2007 annually, and is designed to identify annually a nationally representative sample. The NHANES data include demographic, survey, and laboratory information. Demographic and survey information are collected in a home interview, and all laboratory and physical examination data are collected at a medical visit scheduled at a separate time.

One of the unique advantages to using the NHANES data to generate prevalence estimates is the sampling weights created by the National Center for Health Statistics. The purpose of weighting the NHANES sample data is to permit the analysis of estimates that would have been obtained if the entire sampling frame had been surveyed; in this case, every single child in the USA. Weighting takes into account several features of the surveys: the specific probabilities of selection for the individual domains that were over-sampled (in both the 1999–2000 and 2001–2002 surveys, Mexican Americans and blacks were over-sampled), as well as nonresponse and differences between the sample and the total population.

NHANES III Prevalence Estimates

The first attempts to estimate the prevalence of metabolic syndrome at a population-based level used the NHANES III data [25]. One group of authors defined metabolic syndrome threshold criteria based on the National Cholesterol Education Program's (NCEP) Adult Treatment Panel III adult definition because these criteria had never before been formally defined or applied in children or adolescents [25]. The authors state that in developing a definition for metabolic syndrome in adolescents [43], they considered reference values from the NCEP Pediatric Panel report [44], the American Diabetes Association's statement on type 2 diabetes in children and adolescents [45], and the updated Task Force report on the diagnosis and management of hypertension in childhood [43], as well as on Adult Treatment Panel III [26].

Youth with a waist circumference at or above the 90th percentile value for age and sex were defined as having abdominal obesity. Elevated systolic or diastolic blood pressures were defined as a value at or above the 90th percentile for age, sex, and height, as defined by the National High Blood Pressure Education Program [43]. The NCEP *Report of the Expert Panel on Blood Cholesterol Levels in Children and Adolescents* [44] was used to establish the criteria for cholesterol level abnormalities. The range of 35–45 mg/dL (0.91–1.16 mmol/L) was given for borderline low HDL cholesterol levels for all sexes and ages. In children aged 10–19 years, a borderline high range for triglyceride levels was given as 90–129 mg/dL (1.02–1.46 mmol/L). Therefore, the midpoint value for HDL cholesterol [≤40 mg/dL (≤1.03 mmol/L)] was used as a 10th percentile value, and the midpoint value for triglycerides [≥110 mg/dL (≥1.24 mmol/L)] was taken as the 90th percentile value for age. The reference value for elevated fasting glucose was taken from the American Diabetes Association guideline of 110 mg/dL or higher (≥6.1 mmol/L) [45].

On the basis of these threshold criteria, these authors estimated that nearly 1 million adolescents aged 12–19 in the USA during the late 1980s and the first half of the 1990s, or about 4% of the population of that age, have signs and symptoms of metabolic syndrome [25]. They also found three or more components of the syndrome in 29% of children classified as overweight by the Centers for Disease Control percentile definition (≥95th percentile), in 7% of at-risk adolescents (between the 85th and 95th percentile of body mass index), and in 0.1% of children

with a body mass index (BMI) below the 85th percentile. The prevalence of one and two components of the syndrome was 41% and 14%, respectively. The most common abnormalities were high triglycerides and low high-density lipoprotein (HDL) cholesterol levels. In contrast, the prevalence of high fasting glucose was relatively low at 1.5%.

A second analysis of the same data set (NHANES III) among the same age group also extrapolated the threshold definition from adult criteria, but it differed slightly. Triglyceride and HDL thresholds were taken from equivalent pediatric percentiles [46]. This analysis also defined hyperglycemia using the Adult Treatment Panel III threshold but used a different criterion for waist circumference based on the adult threshold of the 70th percentile [47]. As in the previous analysis, the National Heart, Lung, and Blood Institute's National High Blood Pressure Education Program recommended threshold of the 90th percentile for age, sex, and height was used to define elevated systolic or diastolic blood pressure.

This second analysis showed that low HDL, hypertriglyceridemia, and central obesity were common but that elevated blood pressure and glucose were not. The authors reported that 10% of all US children aged 12–19 years and almost one-third of overweight and obese children had metabolic syndrome. Moreover, two-thirds of all adolescents had at least one metabolic component.

The metabolic syndrome definition implemented by the first group used more restrictive lipid and abdominal waist circumference thresholds, which ultimately lead to the lower prevalence estimates in adolescents (4%). Translating their definition into pediatric percentiles, an HDL level of 40 mg/dL represents the 10th to the 25th percentile in boys and the 10th to the15th percentile in girls, lower than the adult 40th percentile. The higher triglyceride threshold of 110 mg/dL represents the 85th to the 95th pediatric percentile, also higher than the adult 75th to 85th percentile used by the second group. Additionally, the first group used an abdominal circumference threshold of the 90th percentile, whereas the second group used the 75th percentile.

Regardless of their discrepancies in defining metabolic syndrome, these two analyses were the first population-based attempts to identify metabolic syndrome risk in youth. Each analysis indicated that a substantial percentage of US adolescents may be at substantially heightened risk for metabolic syndrome in adulthood and the subsequent risks for type 2 diabetes and premature coronary artery disease, and they ultimately laid the foundation for future NHANES analyses, particularly in light of the obesity epidemic of the last 20–30 years.

Later NHANES Prevalence Estimates

In the time between the publication of the first NHANES III national prevalence estimates and later NHANES samples, namely 1999 and beyond, several smaller clinical studies estimated the prevalence of metabolic syndrome among specific groups of children, such as children in ethnic groups or those who were obese. For

example, Cruz et al. [15] showed that 30% of overweight Hispanic youth had metabolic syndrome, Weiss et al. [27] reported that 39% of moderately obese and 50% of severely obese youth had metabolic syndrome, and Goodman et al. [48], using the adult NCEP criteria, and found that 4.2% of adolescents met these criteria.

Analysis of the NHANES 1999–2002 combined data showed that the prevalence of metabolic syndrome among all US 12-to-19-year-olds ranged from 2.0% to 9.4%, depending on the definition used. Among obese adolescents, the prevalence varied from 12.4% to 44.2%. In the group of obese teens, applying the definition by Cruz et al. [15] produced a prevalence of 12.4%, whereas applying a different definition by Caprio [49] produced a rate of 14.1%. None of the normal weight or overweight teens met either definition. Applying the definition by Cook [25] produced a prevalence rate of 7.8% in overweight teens and 44% in obese teens. The adult definition of metabolic syndrome produced a prevalence rate of 16% in overweight teens and 26% in obese teens.

More recently, an analysis of the NHANES 1999–2006 combined data estimating the prevalence of metabolic syndrome among 12-to-19-year-olds [50] used a definition by Ford et al. [51] that included having three or more of the following five characteristics: a waist circumference above the 90th percentile for age and sex according to the 1988–1994 NHANES III data [52]; either a systolic or a diastolic blood pressure in the 90th percentile for height, age, and sex [53]; a triglyceride concentration of 110 mg/dL or greater (to convert to millimoles per liter, multiply by 0.0113); an HDL-cholesterol concentration of 40 mg/dL or less; and a glucose concentration of 100 mg/dL or greater (to convert to millimoles per liter, multiply by 0.0555). The authors reported that 8.6% of the sample had metabolic syndrome, and approximately half of the participants had at least 1 component. Prevalence was higher in boys (10.8%) than in girls (6.1%), and in Hispanic (11.2%) and non-Hispanic white (8.9%) adolescents than in non-Hispanic black adolescents (4.0%). In non-Hispanic black girls, the prevalence of a large waist circumference was high (23.3%), but no one individual component dominated its diagnosis in non-Hispanic blacks of either sex. Elevated waist circumference, abnormal (high) fasting triglyceride levels, and low HDL serum cholesterol concentrations were the most prevalent components in Hispanic and white adolescents of both sexes, whereas elevated glucose concentrations were prominent among Hispanic and non-Hispanic white boys.

Given the ensuing obesity epidemic among increasingly younger children, we analyzed the 1999–2004 NHANES dataset for 8-to-14-year-olds [1]. We compared in our analysis: (1) a crude profile similar to that used in the NHANES III analysis [25] that included single, non-adjusted threshold points to define elevated blood lipids, waist circumference, and blood glucose, and (2) an age-, sex-, and ethnicity-adjusted profile. All individual component threshold values were based on national standardized norms and were similar to those reported by others [54, 55]. We found that the prevalence of metabolic syndrome among children as young as 8 years old ranged from 2% to 9%, using two age-, sex-, and ethnicity-adjusted definitions [1]. Using a similar (crude) profile for comparison purposes, we found at least three metabolic syndrome components in 9% of 12-to-14-year-olds (about twice the 4% reported by Cook et al. [25]) and in 44% of those who are overweight (again, about

twice the 29% reported by Cook). This relative doubling of the prevalence of obesity and overweight in the past 10 years has been reported elsewhere [56–58], yet few have reported associated cardiovascular disease risk factors, particularly in large numbers of 8-to-11-year-olds. Regrettably, our data showed that the prevalence of overweight in the younger children was similar to that of the older children.

Our higher prevalence rates may be the result of classification differences; namely, our use of the 75th percentile as a threshold for waist circumference for the adjusted profile rather than the 90th percentile as used in other studies [25]. Interestingly, the authors [52] who generated the standardized waist circumference threshold values for the US pediatric population that we used stated "Based on these values, the careful attention to children and adolescents with waist circumference values that fall on the 75th and 90th percentile, according to their ethnic classification and sex, becomes important in the identification—and prevention—of children at risk for various comorbidities, including cardiovascular disease, hyperinsulinemia, and type 2 diabetes [59]." On the basis of their recommendations, on previous authors' [27] use of the 75th percentile as a threshold for waist circumference, and on the probability that these current 75th percentile values are similar to those of the 90th percentile only 20 years ago as a result of the current obesity epidemic, our goal with this work was to help move the field forward by presenting an analysis that differed from previous studies yet still addressed the lack of a consensus for a definition of metabolic syndrome in children.

Other Regional-Based Sample Estimates

As stated above, describing the smaller clinic-based prevalence estimates of metabolic syndrome in children and adolescents is beyond the scope of this chapter. This issue becomes more complicated given the large number of definitions of the syndrome[60]. A recent exhaustive literature review on the pediatric definitions of the syndrome found at least 27 articles with 46 definitions of the syndrome, most of them unique [49, 60]. The following section summarizes a few of the better-known and larger cohort studies in the USA.

The Bogalusa Heart Study [32], a regional, longitudinal study of cardiovascular disease risk factors in black and white children ages 5–17 years old, defined metabolic syndrome as having four components greater than the 75th percentile for age and sex derived from their own population data. Based on this definition, the prevalence of metabolic syndrome was 4% among white children and 3% among black children [33].

Similarly, the Cardiovascular Risk in Young Finns Study [61], another large multicenter study of risk factors for heart disease in children and young adults, found the prevalence to be 4% among children aged 6–18 years old.

Goodman et al. [48] determined the prevalence of metabolic syndrome among adolescents by using definitions from the NCEP's Adult Treatment Panel III and World Health Organization (WHO) guidelines. The WHO definition requires

either insulin resistance, hyperglycemia, or known diabetes. In addition to this requirement for WHO-defined metabolic syndrome, two of three other risk factors had to be present: hypertension, dyslipidemia (hypertriglyceridemia or low HDL cholesterol), and central obesity (a high waist circumference, or a BMI ≥ 30). In contrast, to have NCEP-defined metabolic syndrome, three of five possible risk factors had to be present, including hypertension, low HDL cholesterol, hypertriglyceridemia, hyperglycemia, or high waist circumference. Risk-factor thresholds were those used for adults, except in relation to obesity, which was defined by the established and widely used epidemiologic definition in adolescence of a BMI at or above the 95th percentile. The study analyzed a school-based, cross-sectional sample of 1,513 black, white, and Hispanic teenagers who had a fasting morning blood sample drawn and a physical examination. The prevalence of metabolic syndrome was 4.2% by the NCEP definition and 8.4% by the WHO definition. The syndrome was found almost exclusively among obese teens, for whom the prevalence was 20% by the NCEP definition and 39% by the WHO definition.

International Pediatric Metabolic Syndrome Prevalence Estimates

There has been an increased volume of studies focused on adolescent metabolic syndrome internationally, paralleling the global obesity epidemic. According to these studies, prevalence rates for children in Asia remain below those in the USA. Using De Ferranti's definition of pediatric MetS, while 10% of children in the USA suffer from metabolic syndrome, the rate is 6.6% for their Chinese counterparts [62]. Additionally, 2.5% of Korean adolescents between the ages of 12 and 19 suffer from the IDF-defined metabolic syndrome, in contrast to USA's rate of 5.5% [63].

A study conducted in Guangzhou, China suggests that Asian adults generally have a higher body fat percentage than adults in the USA and therefore calls for race-specific percentile cut points [62]. The BIG study, which included samples of children and adolescents in Brazil, Iran, and Germany, identified a variety in the prevalence of the individual components based on respective ethnicities. These findings therefore called for an examination of the role of genetics [64]. Research should eventually help guide pediatric clinical practice by clarifying the predictive value of using an ethnic-specific definition or a "one-definition–fits-all" approach to metabolic syndrome.

Secular Trends in Metabolic Syndrome Throughout the Lifespan

Secular trends and longitudinal studies have shown that cardiometabolic disease risk factors that are present in childhood predict adult disease. The Princeton Lipid Research Clinics Follow-up study showed that over 30 years, the risk for cardiovascular

disease was 9 times as high, and that for type 2 diabetes mellitus was 4 times as high, in children with metabolic syndrome than in children without the syndrome, after adjusting for age, sex, ethnicity, and family history [65]. This same study reported that differences between adults with and without metabolic syndrome first occurred at ages 8 and 13 for BMI and at ages 6 and 13 for waist circumference in boys and girls, respectively [2]. The authors concluded that children with BMI and waist circumference values exceeding the established criterion values are at increased risk for the adult metabolic syndrome.

In the Cardiovascular Risk in Young Finns Study, one of the first studies to explore childhood predictors of metabolic syndrome, fasting insulin at baseline was related to the development of the syndrome after a 6-year follow-up of 1,865 children and adolescents 6–18 years old. Baseline insulin concentration was higher in children who subsequently developed metabolic syndrome, lending support to the theory that insulin resistance precedes the development of the syndrome in childhood [52].

More recently, the Bogalusa Heart Study explored the relationship of childhood obesity (as measured by BMI) and insulin resistance (as measured by fasting insulin levels) on the risk of developing metabolic syndrome as an adult [66]. Researchers followed 718 children ages 8–17 at baseline for an average of 11.6 years. They defined metabolic syndrome as having four of the following: a BMI, fasting insulin, systolic or mean arterial blood pressure, and a triglycerides/HDL ratio in the highest quartile for age, sex, ethnicity, and study year. The highest childhood BMI and insulin quartiles were significantly related to the incidence of risk-factor clustering in adulthood. More specifically, children in the top quartile for BMI and insulin versus those in the bottom quartile were 11.7 and 3.6 times, respectively, more likely to develop the clustering of factors that defines metabolic syndrome as adults. A high childhood BMI was significantly associated with adult onset of the syndrome, even after adjusting for childhood insulin levels, suggesting that childhood-onset obesity can predict the development of metabolic syndrome in adulthood.

Despite differences in the definition of metabolic syndrome in the studies reviewed above, overall findings suggest that both obesity and insulin resistance contribute to the development of the syndrome during childhood.

The current epidemic of obesity and increased prevalence of type 2 diabetes mellitus in adolescents with its attendant consequences is a clinical and public health priority because interventions that target cardiometabolic risk in youth are more easily instituted than are those to modify behaviors later, when deleterious health habits are established [44]. However, given the current prevalence of childhood and adolescent obesity, it is unlikely that this major public health problem can be managed solely in clinical settings. Rather, public health strategies must be integrated into home and family, school, and community-based settings. Currently, the USA allocates substantially more resources to the adult obesity epidemic than to preventive strategies among children and adolescents. Clearly, prevention strategies for both age groups must take into account the causal factors of obesity that begin in childhood.

Future Projections

For the first time in decades, the life expectancy of Americans is projected to *decrease* as a consequence of obesity alone [67]. Furthermore, given the current obesity epidemic among adolescents, it is most likely that in a decade, the country will be dealing with a young adult population facing potential chronic disease. Yet, we do not know the potential lifelong consequences of being obese and having metabolic syndrome as a child. Learning more about how eating and physical activity patterns develop through infancy, childhood, and adolescence and how they track into adulthood should improve the effectiveness of obesity prevention strategies and interventions.

Clearly, the current adolescent obesity epidemic, if left to continue on into adulthood, will indirectly affect all Americans because it undoubtedly will take a heavy toll on the health-care system. For example, a December 2004 report from Feinberg School of Medicine at Northwestern University in Chicago found that for men, the total average annual Medicare charges for those not overweight were $7,205, for the overweight $8,390, for the obese $10,128, and for the severely obese $13,674. The total average annual charges for women in the same four categories were, respectively, $6,224, $7,653, $9,612, and $12,342. The annual average Medicare charges for severely obese men were $6,469 *more* than for non-overweight men, and for severely obese women, annual average charges were $5,618 *more* than for women not overweight [68].

Conclusions

The possibility of becoming obese is greater than ever for US children and adolescents. If current prevalence trends continue, our children will grow up to be the most obese generation of adults in US history, faced at increasingly younger ages with the onset of chronic conditions, such as metabolic syndrome, which in turn will lead to chronic and costly outcomes, such as diabetes and cardiovascular disease. However, even more troubling is that before reaching adulthood, as we have clearly shown here, large proportions of overweight and obese children are already experiencing substantial medical effects related to their overweight in the form of metabolic syndrome.

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