Identifying Children at Risk for Obesity, Type 2 Diabetes, and Cardiovascular Disease

In 1998, the World Health Organization (WHO) designated obesity as a global epidemic affecting adults and children. In general, obesity is defined as the degree of somatic overweight that affords detrimental health consequences. This definition does not contemplate a specific cut-off point, but it allows health care providers to consider individual predisposition when assessing at-risk children, including underlying conditions, family history, medications, and lifestyle. Within the scientific community, the discovery of leptin and the elucidation of disorders affecting various neuroendocrine pathways and the genetic linkages of obesity have promulgated the notion that obesity is a disease.

BMI is the accepted measure of obesity in children and adolescents. In childhood, comparison of BMI to normal curves for age and sex allows for categorization of BMI above the 85th percentile as overweight and above the 95th percentile as obese.

In the United States, the most recent estimates of obesity prevalence are based on data from the 1999–2000 National Health and Nutrition Examination Survey (NHANES IV). NHANES IV demonstrated that 20.6% of 2- to 5-year-old children in the United States were overweight. In older children, this prevalence was even higher, with 30.5% of 6- to 11-year-old children and 30.4% of adolescents (12–19 years of age) being overweight. The prevalence of obesity among children aged 0–23 months, 2–5 years, 6–11 years, and adolescents was 11.4, 10.4, 15.3, and 15.5%, respectively.

This epidemic equally affects both sexes, and its prevalence has increased compared to data from the previous NHANES reports in all age ranges and racial groups. However, minorities are over-represented in this epidemic. For instance, the prevalence of obesity among African-American (23.6%) and Hispanic (23.4%) adolescents is twice that among white adolescents (12.7%), and the rate of increase in the prevalence of obesity among African-American and Hispanic adolescents almost doubled between the periods 1988–1994 and 1999–2000, from 13.4 to 23.6% in African Americans and from 13.8 to 23.4% in Hispanics.

Obesity has overtaken AIDS and malnutrition as the top health problem in the world. Obesity markedly reduces life expectancy, especially among younger individuals. Severely obese (BMI > 45 kg/m²) young adults have a reduced life expectancy of 5–20 years. Childhood obesity often persists into adulthood and has been independently associated with subsequent morbidity and mortality in adulthood. However, the sequelae of obesity are not limited to adulthood,
as evidenced by the increased incidence of concomitant comorbidities seen in overweight youth (Table 1). It has been suggested that because of the health impact of obesity, this generation may be the first to live a shorter average lifespan than the preceding generation.

It has been well demonstrated that cardiovascular risk factors frequently occur in obese youth and that these risk factors tend to cluster. Obesity and insulin resistance are hypothesized to be the underlying mechanism for this clustering of risk factors, known as the metabolic syndrome. Central adiposity, atherogenic dyslipidemia, hypertension, insulin resistance, glucose intolerance, and a prothrombotic, pro-inflammatory state characterize the metabolic syndrome.

Clinical criteria for defining the metabolic syndrome in adults have been developed by the WHO and the National Cholesterol Education Program Adult Treatment Panel III. In adults, specific cut-off points have been delineated for these clinical criteria of waist circumference, systolic and diastolic blood pressure, serum triglycerides and HDL cholesterol, and fasting glucose. Several studies have examined the frequency of the metabolic syndrome in youth based on components of the adult criteria. The lack of standardized criteria and cutpoints for defining the metabolic syndrome in youth makes comparisons across studies difficult. Despite the use of diverse criteria and cutpoints, results from these studies substantiate that the metabolic syndrome is already highly prevalent among obese children and adolescents.

Population-based data suggest that the epidemic of pediatric obesity is being followed by an increase in type 2 diabetes, particularly in adolescents of minority groups. The American Diabetes Association estimates that between 8 and 45% of children newly diagnosed with diabetes have type 2 diabetes. In the greater Memphis, Tenn., area, the authors have reported a fivefold increase in childhood type 2 diabetes between 1990 and 2001, with type 2 diabetes accounting for 43% of the newly diagnosed cases in 2000 and overweight African-American adolescents accounting for roughly 86% of the new cases.

As a consequence of this epidemic, annual hospital costs for obesity and obesity-associated conditions in youth (6–17 years of age) increased from $35 million during the period from 1979 to 1981 to $127 million during the period from 1997 to 1999. A relationship has been found between BMI in young adulthood and middle age to subsequent health care expenditures at ages ≥ 65 years. Age- and race-adjusted cardiovascular disease (CVD)-related, type 2 diabetes-related, and total charges were significantly higher for overweight and obese adults. Total charges for severely obese men and women were $6,192 more (84% higher) and $5,618 more (88% higher), respectively, than for nonoverweight subjects. If the trend in obesity-associated type 2 diabetes and cardiovascular risk factors continues in children, national expenditures for health care are likely to escalate.

Based on the current set of evidence, we speculate that in genetically susceptible populations, the interaction of racial, sociocultural, and biological factors, triggered or exacerbated by concomitant obesity, ultimately leads to early development of type 2 diabetes and increased risk for CVD in youth. In this review, we hope to provide useful information to assist health care providers in identifying those individuals more vulnerable to becoming obese and developing associated comorbidities.

Identifying Children at High Risk for Obesity, Type 2 Diabetes, and CVD
Prevention of childhood obesity is critical because obesity is associated with the development of unfavorable health outcomes during childhood and adulthood. It has been overemphasized that the major etiopathogenic factors contributing to obesity result from an imbalance in the energy equation produced by either increased energy intake or decreased energy expenditure or both. This notion has led health providers to develop a simplistic perception that societal and nutritional changes (i.e., “the toxic environment”) are the chief parameters that foster the current epidemic of obesity, type 2 diabetes, and CVD in children.

However, this imbalance in the energy equation does not explain differences in fat distribution, individual susceptibility to develop obesity-associated comorbidities, or the dissimilar weight loss response to lifestyle and pharmacological interventions. Compared to that in adults, the energy balance in children is more affected by the intrauterine environment, metabolic abnormalities, racial and genetic predisposition, underlying conditions, medications, and other factors. The interactions of these factors with social and environmental forces clearly denote differences between children and adults.

How and when to intervene to prevent obesity in childhood is a challenging question. The rapid increase in the prevalence of childhood overweight and its potential effect on morbidity and mortality in childhood and adulthood underscores the importance of identifying critical periods for the prevention of overweight in vulnerable populations and of developing an understanding of factors that cause excess weight gain. A critical period for overweight or obesity is defined as a time when the risk of onset, complications, or persistence of overweight or obesity is increased.

Risk factors associated with the

### Table 1. Complications of Obesity

<table>
<thead>
<tr>
<th>Metabolic</th>
<th>Mechanical</th>
<th>Psychosocial</th>
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<tbody>
<tr>
<td>• Diabetes</td>
<td>• Sleep apnea/hypoventilation</td>
<td>• Depression</td>
</tr>
<tr>
<td>• Metabolic syndrome</td>
<td>• Pseudotumor cerebri</td>
<td>• Eating disorders</td>
</tr>
<tr>
<td>• Hypertension</td>
<td>• Slipped capital femoral</td>
<td>• Anxiety</td>
</tr>
<tr>
<td>• Lipid abnormalities</td>
<td>• Kidney structural abnormalities</td>
<td>• Deterioration of social interactions</td>
</tr>
<tr>
<td>• CVD</td>
<td>• Cardiomyopathy</td>
<td></td>
</tr>
<tr>
<td>• Cancer</td>
<td>• Degenerative arthritis</td>
<td></td>
</tr>
<tr>
<td>• Infertility</td>
<td>• Flat feet</td>
<td></td>
</tr>
<tr>
<td>• Hyperandrogenism</td>
<td>• Blunt disease</td>
<td></td>
</tr>
<tr>
<td>• Polycystic ovarian disease</td>
<td>• Respiratory disease</td>
<td></td>
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<tr>
<td>• Gout</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Gallbladder disease</td>
<td></td>
<td></td>
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<tr>
<td>• Hypercoagulability</td>
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</table>
antenatal environment, the early postnatal years, adiposity rebound (5–6 years of age), and puberty have been identified within different critical periods for the development of obesity (Table 2). Health providers should recognize these critical periods in the development of children during which interventions may successfully prevent obesity.

Factors associated with the antenatal environment and the fetus appear to be important components in the development of childhood obesity, type 2 diabetes, and CVD. Effects of the intrauterine environment on cell numbers, satiety centers in the brain, and endocrine function represent mechanisms that may logically account for the apparent prenatal channeling of either restricted or exuberant growth.9 The fetal origins hypothesis, as proposed by Barker et al.,10 suggests that antenatal stress or placental insufficiency “programs” metabolic alterations in β-cell function and insulin sensitivity that persist into adult life and promote the development of the metabolic syndrome. Third-trimester amniotic fluid insulin levels have been related to childhood obesity, insulin resistance, and systolic hypertension.11 Food deprivation in early pregnancy also has been suggested as an independent risk factor for obesity in adults.10 A relationship between small-for-gestational-age infants and the development of obesity, cardiovascular complications, and type 2 diabetes has been demonstrated, particularly in minority populations. Conversely, large infants, most commonly a result of gestational diabetes mellitus, also exhibit increased risk for the development of obesity, cardiovascular complications, and type 2 diabetes.9,10

Parental obesity is also an important predictor of childhood obesity. Prepregnancy maternal weight and BMI and maternal weight gain during pregnancy have been independently associated with increased risk of childhood obesity and associated conditions.11 Macrosomia of obese mothers exhibit enhanced insulin resistance, as suggested by higher serum lipids, lipoprotein apolipoprotein (apo) B100, and apo (A-1).12

Children with at least one overweight parent at the age of adiposity rebound have a four- to fivefold greater chance of becoming obese adults.13 Lean children ≤ 5 years of age have a 13-fold risk of adult obesity if both parents are obese, suggesting that genetic influences predominate in childhood weight gain. Obesity, type 2 diabetes, and CVD often run in families, particularly in minorities with lower socioeconomic backgrounds.

Postnatal factors, including infant overnutrition, play an extremely important role in the future development of obesity. A pattern of rapid weight gain during the first 4 months of life also has been associated with an increased risk of overweight status at age 7 years, independent of birth weight and weight attained at age 1 year.14 Early overnutrition has been correlated with elevated leptin concentrations, a marker of adiposity in later life.15 Differences in both volume and composition of commercial formula compared to breast milk have also been proposed as etiological factors of childhood obesity.11 Some evidence suggests that the rate of weight gain during the first few months of life and related determinants, such as type of infant feeding, may influence weight status later in childhood as well as the later development of adult CVD. The prevalence of obesity in children who were never breastfed was 4.5%, compared to 2.8% in breastfed children, and a clear time-response effect was identified for the duration of breastfeeding on the decline in prevalence of obesity.16

The age of adiposity rebound, the point of the BMI nadir before body fatness begins to increase (between 5 and 6 years of age) is also an important predictor for adult obesity.13 Children with early adiposity rebound have a fivefold greater chance of becoming obese as adults, compared to those with late adiposity rebound. At the age of adiposity rebound, children who are already overweight have a sixfold greater risk for adult obesity compared to lean children. Therefore, the earlier the onset of childhood obesity, the greater the risk of adult obesity.

Of special consideration are children with pre-existing diseases, who often require the use of medications that may stimulate weight gain.17 The recognition of medications that induce weight gain may be an efficient measure to identify children at risk of obesity. Medication-induced weight gain is often overlooked and may be associated with an increased risk of complications, such as diabetes, asthma, hypertension, and depression. Although not every patient will gain weight while receiving treatment with drugs known to promote weight gain, many will. Health care providers should monitor weight as part of routine assessment. They should be aware of the impact of even a small increase in weight and make appropriate adjustments to the medication regimen or lifestyle. Drugs that have been associated with weight gain and that are often used in children with underlying conditions are listed in Table 3.

The BMI chart is a valuable predictive device and should be used with all children. The higher the BMI during childhood, the more likely adult obesity will manifest. In general, children with a BMI ≥ the 95th percentile have a high risk for adult obesity. Children and adolescents with BMI ≥ the 95th percentile have a 62–98% chance of being obese at 35 years of age.18 This risk increases as the child becomes older. Change in BMI during and after adolescence is the most important predictive variable for adult obesity.19 Obese adolescents (15–17 years of age) have 17.5 times greater odds of becoming obese adults compared to normal-weight peers, whereas obese 1- to 2-year-olds have a 1.3 times greater odds of becoming obese adults compared to normal-weight toddlers.

### Table 2. Risk Factors Associated With the Development of Obesity

#### Antenatal Factors
- Placental insufficiency
- Elevated insulin levels in amniotic fluid
- Food deprivation in early pregnancy
- Gestational diabetes
- Maternal overweight pre-pregnancy
- Maternal weight gain during pregnancy
- Parental history of overweight
- Smallness for gestational age (macrosomia baby)

#### Postnatal Factors
- Infant overnutrition
- Bottle feeding
- Type of infant formula
- Rapid weight gain during first 4 months of life
- Early adiposity rebound
- Drug-induced weight gain
- Overweight in adolescence
Table 3. Medications That Promote Weight Gain in Children

<table>
<thead>
<tr>
<th>Classification</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antidiabetics</td>
<td>Insulin, sulfonylureas, meglitinides, thiazolidinediones</td>
</tr>
<tr>
<td>Tricyclic antidepressants</td>
<td>Amitriptyline, imipramine, desipramine, nortriptyline</td>
</tr>
<tr>
<td>Monoamine oxidase inhibitors</td>
<td>Phentolamine, isocarboxazid</td>
</tr>
<tr>
<td>Mood stabilizers, antiepileptics</td>
<td>Lithium, valproic acid, carbamazepine, gabapentin</td>
</tr>
<tr>
<td>Selective serotonin reuptake inhibitors</td>
<td>Paroxetine, sertraline</td>
</tr>
<tr>
<td>Atypical antipsychotics</td>
<td>Clozapine, olanzapine, risperidone, quetiapine, ziprasidone</td>
</tr>
<tr>
<td>Tetracyclic antidepressants</td>
<td>Mirtazapine</td>
</tr>
<tr>
<td>β-Blockers</td>
<td>Propranolol</td>
</tr>
<tr>
<td>Calcium channel blockers</td>
<td>Nifedipine, verapamil</td>
</tr>
<tr>
<td>Corticosteroids</td>
<td>Dexamethasone, prednisone, flunisolide, fluticasone</td>
</tr>
<tr>
<td>Anticonceptives</td>
<td>Oral birth control pills, Depo-Provera</td>
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**Childhood Obesity as a Precursor for Type 2 Diabetes and CVD**

There is solid information showing that type 2 diabetes and risk factors for CVD have increased in children, particularly in obese adolescents. Adipose tissue is a metabolically active endocrine organ producing a large number of hormones, peptides, and small molecules that affect metabolism and cardiovascular regulation. These include inflammatory cytokines, thrombogenic and inflammatory markers, and vasoactive substances that contribute directly or indirectly to changes in vasculature and CVD.

Chronic, subclinical inflammation may be one pathophysiological mechanism explaining the increased risk of atherosclerotic CVD and diabetes associated with obesity. Adipose tissue expresses inflammatory cytokines and stimulates the release of inflammatory and thrombogenic markers, such as C-reactive protein (CRP) and fibrinogen, which contribute to the development of fatty streaks and more advanced atherosclerotic lesions. Leptin may increase platelet aggregation and arterial thrombosis. It has been suggested that flux in free fatty acids (FFAs) promotes thrombosis through alterations in protein C, plasminogen activator inhibitor-1 (PAI-1), and enhanced platelet aggregation. Elevated levels of FFAs alter the matrix of endothelial cell basement membranes, making them more permeable to macromolecules. Diets high in saturated and trans fatty acids promote hypercholesterolemia. Macrophages and arterial smooth muscle cells more readily take up LDL cholesterol, especially small dense LDL particles, contributing to the development of atherosclerotic lesions. An LDL particle linked to an apo(a) polypeptide chain, lipoprotein(a), may inhibit endogenous fibrinolysis and be a marker for thromboembolic disease, particularly in youth.

Several cross-sectional studies have examined established cardiovascular risk factors in overweight and lean youth. Compared to lean peers, overweight youth are more likely to have lipid abnormalities and elevated blood pressure. Both overweight severity and central (abdominal) adipose distribution are associated with cardiovascular risk factors and development of glucose intolerance in adults, with abdominal adiposity, particularly visceral fat mass, considered to be more deleterious than peripheral fat mass. In youth, central fat distribution, whether measured by waist circumference or waist-to-hip ratio, is related to adverse lipid and lipoprotein levels and higher blood pressure. Greater intra-abdominal fat mass has also been shown to correlate with higher basal insulin, higher triglyceride levels, higher blood pressure, and lower HDL cholesterol and apo (A-1) levels in adolescents. However, the lack of age- and sex-specific normative values for waist circumference or waist-to-hip ratios among children makes it difficult to identify which youth are at greater risk for developing these obesity-associated conditions.

Physical inactivity is recognized as a risk factor for obesity, CVD, and type 2 diabetes. In a predominantly white group of 610 9- to 18-year-olds, higher levels of cardiorespiratory fitness and habitual physical activity were associated with more favorable levels of triglycerides, LDL and HDL cholesterol, fasting glucose, and blood pressure. In contrast, a study of 82 African-American sixth graders found no significant relationships between blood pressure and physical activity or adiposity. However, others have reported modest associations between blood pressure and cardiorespiratory fitness and BMI in a multiethnic cohort of 11- to 14-year-olds. These inconsistencies may be partially attributed to the varying methods of measuring physical activity and the use of absolute values for blood pressure and lipid levels rather than age-adjusted values. Our work suggests that both cardiovascular fitness and severity of overweight contribute to cardiovascular risk in African-American youth, with the percentage of overweight and cardiorespiratory fitness accounting for 34% of the variance in the cardiovascular risk profile.

Defects of insulin secretion, insulin action, hepatic glucose production, or combinations of these mechanisms characterize childhood type 2 diabetes. These defects are likely triggered or exacerbated by concurrent obesity, sedentary lifestyle, unhealthy eating habits, and hormonal changes (puberty) in genetically susceptible populations that ultimately could lead to β-cell failure and the appearance of glucose intolerance and diabetes. Decreased insulin sensitivity (insulin resistance) has been shown to precede the development of type 2 diabetes and CVD. Several mechanisms link excess of adiposity with insulin resistance, including insulin signaling abnormalities, adipokines, sedentary behavior, nonesterified fatty acids, and ectopic fat infiltration. In vulnerable individuals, transient changes associated with puberty, including increase in fat mass, insulin resistance, leptin, growth hormone, and IGF-1.
may further exacerbate the impact of obesity on glucose and lipid metabolism, fostering type 2 diabetes and increasing the risk of early CVD.

Assessing the Risk of Type 2 Diabetes and CVD in Overweight Children

The progression of childhood obesity into adulthood is associated with early development of complications, including type 2 diabetes and CVD. This suggests that the pathogenic process involved in the development of such conditions starts during childhood. In order to provide appropriate care, clinicians and other health care providers face several challenges, including lack of well-validated assessment algorithms, very limited long-term treatment experience, and few approved tools for the treatment of childhood obesity and associated complications. Efforts to identify the negative impact of obesity at its incipient stages may justify early and more aggressive treatment intervention to prevent the progression and development of complications.

Health providers taking care of obese children require a practical and objective way to assess the severity and progression of overweight in children who are still growing. The current consensus is that BMI is a valid and feasible indirect measure of body fatness. The BMI cutoff points are linked to adult cutoff points for overweight and obesity, which are good indicators of risks for adverse health outcomes. They correlate with markers of obesity-related complications, including blood pressure, lipid profile, and insulin resistance, as well as with long-term mortality.

BMI is simple to use, consistent for children and adolescents, and very useful in clinical practice and in epidemiological studies. However, it suffers from a number of limitations. BMI cutoff points do not permit comparison of severity of overweight across age and sex groups, nor do they provide a comprehensive way to longitudinally follow overweight in youth. In children and adolescents, BMI cutoff points are constantly changing, and they are expected to progressively increase until reaching adult BMI values (~18 years of age).

The team at the Lifestyle Clinic at LeBonheur Children's Medical Center in Memphis, Tenn., has validated the use of the relative BMI (RBMI) as a clinical estimation of the percentage of overweight above the ideal BMI percentile. RBMI is an objective way to assess and compare changes to any intervention in our overweight population. RBMI is calculated using the following equation: BMI ÷ BMI at 50th percentile for age and sex × 100.

We have found that both BMI and RBMI are similarly associated with indexes of glucose metabolism and insulin dynamics and cardiovascular risk factors in our population. RBMI transforms BMI into a continuous variable relative to the ideal reference value (50th percentile on age- and sex-specific BMI charts) that reflects the severity of overweight, allowing a comparison across age and sex groups based on severity of overweight and facilitating longitudinal follow-up. Our experience supports the notion that estimating the severity of overweight by RBMI could aid clinicians assessing the magnitude and progression of overweight at different time-points of the growing period in an objective and practical way.

Presently, the lack of clinical indicators to identify youth at higher risk of developing impaired glucose tolerance (IGT) or type 2 diabetes precludes clinicians from early intervention to stop its progression. Commonly, referrals for glucose tolerance testing in severely obese children are triggered by the development of symptoms rather than geared toward identification of children at risk who could benefit from early intervention. Using a standardized screening protocol for high-risk groups, we have found a fourfold higher prevalence of abnormalities in glucose metabolism in youth with BMIs between the 85th and 95th percentiles.

There is not definitive agreement about which screening tests best reflect the negative impact of increased adiposity on glucose metabolism in adolescents. Screening recommendations favor fasting blood glucose (FBG) as the ideal screening method in subjects at risk for IGT or type 2 diabetes because of its low cost and greater convenience. However, we agree with a growing set of evidence suggesting that a single FBG may not reflect the early impact of increasing adiposity on glucose homeostasis nor discriminate between youth with and without IGT/type 2 diabetes until significant deterioration in glucose metabolism has occurred. Abnormalities in post-prandial blood glucose typically precede deterioration in FBG. It has been shown that FBG is a poor predictor of diabetes in obese adolescents and subjects with polycystic ovarian syndrome. In agreement with these investigations, we have reported that ~66% of severely overweight adolescents with IGT during the oral glucose tolerance test (OGTT) and have an FBG value < 100 mg/dl at the time of their initial evaluation. Therefore, the opportunity for earlier intervention in these adolescents will be missed.

Simple methods of assessing insulin sensitivity and secretion are important in the evaluation and follow-up of youth with obesity and risk factors for type 2 diabetes. The OGTT is a clinically and widely used procedure originally developed to classify carbohydrate tolerance. The effectiveness and reliability of the OGTT to establish the diagnosis of IGT/type 2 diabetes have been demonstrated in children. Plasma glucose and insulin response during the OGTT reflect the ability of pancreatic β-cells to secrete insulin and the sensitivity of tissues to insulin. Therefore, many investigators have studied and validated simple surrogate indexes of β-cell function and insulin resistance in children and adults based on values obtained during the OGTT (Table 4). The OGTT-derived indexes provide clinically useful information that allows the estimation of insulin secretion capacity and insulin sensitivity, both of which are essential for defining the treatment approach. Indexes reflecting β-cell secretion capacity clearly help clinicians to demonstrate that β-cell workload increases with overweight. However, these β-cell indexes are not good predictors for type 2 diabetes because overweight adolescents with glucose intolerance show insulin secretion capacity at a level that is at least equivalent to those with normal glucose tolerance.

We agree with other investigators that the accuracy of surrogate estimates of β-cell function may be diminished once IGT is present. Conversely, indexes reflecting insulin sensitivity clearly support the notion that deterioration of insulin sensitivity with increasing overweight could be the most important pathogenic factor leading to IGT among adolescents.

We have found that adolescents at even moderate levels of overweight have already experienced a pronounced reduction in insulin sensitivi-
Summary
Greater body weight predisposes children to many of the medical complications of obesity found in adults, in particular components of the metabolic syndrome: hypertension, dyslipidemia, and impaired glucose metabolism. As these children age, the obesity epidemic will lead to epidemics of diabetes, hypertension, and CVD. However, not all overweight adolescents have the same risk of developing these complications. Appropriate risk stratification could guide clinicians to recognize overweight youth who are at higher risk of developing type 2 diabetes or CVD and lead to prompt intervention. Stratification of adolescents based on 1) severity of overweight (RBMI), 2) estimates of $\beta$-cell activity and insulin resistance (OGTT-derived indexes), and 3) cardiovascular risk profile may be useful for the longitudinal follow-up of overweight youth. Health care providers of overweight children need to pursue efficient screening procedures earlier in the progression of overweight in order to prevent adolescents from developing these diseases.

Table 4. Formulas of β-cell Insulin Secretion Indices and Insulin Sensitivity Indexes

<table>
<thead>
<tr>
<th>Indexes</th>
<th>Formulas</th>
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<tbody>
<tr>
<td><strong>β-cell Activity</strong></td>
<td></td>
</tr>
<tr>
<td>CIR30</td>
<td>$I_g \times 100 \left[ \frac{G_{30}}{(G_{30} - 70)} \right]$</td>
</tr>
<tr>
<td>Insulinogenic index</td>
<td>$\frac{I_{30} - FI}{G_{30} - FBG}$</td>
</tr>
<tr>
<td><strong>Insulin Sensitivity</strong></td>
<td></td>
</tr>
<tr>
<td>CISI</td>
<td>$\sqrt{\frac{(FI \times FBG) \times (mean insulin (0–120 min) \times mean glucose (0–120 min))}{10,000}}$</td>
</tr>
<tr>
<td>QUICKI</td>
<td>$\frac{1}{\log \frac{FI}{\mu U/ml}} + \log FBG$</td>
</tr>
<tr>
<td>HOMA</td>
<td>$\frac{(FBG_{mmol} \times FI_{\mu U/ml})}{22.5}$</td>
</tr>
</tbody>
</table>

HOMA, homeostasis model assessment; QUICKI, quantitative insulin-sensitivity index.

ty.50 Deterioration of insulin sensitivity has been shown to be one of the best predictors of IGT and type 2 diabetes in adolescents, and severity of overweight is the major cause of such deterioration ($R^2 = 0.39, P < 0.001$).39 We have reported that overweight adolescents with a composite insulin sensitivity index (CISI) (Table 4) $< 2.0$ were 10 times more likely to have IGT than overweight adolescents with a higher CISI.

Although studies link childhood obesity to cardiovascular risk factors that predict CVD,21,22 screening is not routinely performed in obese youth. Recommended screening for cardiovascular risk factors in obese youth includes measurement of blood pressure, fasting insulin and glucose, and traditional lipoprotein analysis; however, these measures may underestimate cardiovascular risk, particularly in adolescent minorities. Fasting levels of insulin and glucose do not reflect the hyperinsulinemia that occurs during adolescence or the racial differences reported during stimulated glucose tolerance testing.33 Despite having a higher incidence of CVD, African Americans may not exhibit the same magnitude or frequency of traditional lipid abnormalities as their white counterparts.21 In severely obese African-American youth, we found that established cardiovascular risk factors of elevated total and LDL cholesterol occurred, respectively, in 48 and 33% of the youth. Hypertriglyceridemia and low HDL cholesterol, components of the metabolic syndrome, occurred less frequently (13 and 24%, respectively), whereas hypertension (values $> 95$th percentile based on norms for age, sex, and height) was present in 50% of the youth.37

Chronic, subclinical inflammation has been identified as one mechanism explaining the increased risk of obesity-associated CVD and diabetes. This awareness has lead to an increased interest in emerging markers of cardiovascular risk, such as CRP, fibrinogen, and PAI-1. A number of studies have examined relationships between obesity and these emerging cardiovascular risk factors in children. In youth, severity of obesity assessed by fat mass was associated with increased levels of fibrinogen52 and CRP.53 We found that 43% of obese youth had elevated CRP, and 38% had elevated fibrinogen, despite having normal LDL cholesterol levels.31

These findings suggest that the current screening recommendations may underestimate risk for CVD and diabetes in severely overweight youth, particularly adolescent minorities. We recommend assessment of glucose tolerance by the OGTT and determination of insulin sensitivity using OGTT-derived indexes. Accurate comparison of resting blood pressure to normative values based on age, sex, and height resulted in identification of hypertension in 50% of youth who were referred to our clinic as “healthy” children for weight management. Emerging risk factors for CVD may provide helpful information beyond that provided by the lipid profile in overweight minority youth.

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References


7Goran MI, Ball GD, Cruz ML: Obesity and risk of overweight in childhood and adolescence. Am J Clin Nutr 75:993–999, 2002


28Burghen G, Cowan PA, Christensen M, Markell S, Umpierrez GE, Velasquez P: Insulin sensitivity deterioration may be the most important factor in the pathogenesis of type 2 diabetes (T2DM) among adolescents. Diabetologia 46 (Suppl. 2):A26, 2003


32Matsuda M, DeFronzo RA: Insulin sensitivity indices obtained from oral glucose tolerance testing: comparison with the euglycemic insulin clamp. Diabetes Care 22:1462–1470, 1999

33Conwell LS, Trost SG, Brown WJ, Batch JA: Indexes of insulin resistance and secretion in


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