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Obesity, Metabolic Syndrome, and Insulin Resistance in Minority Urban High School Students

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Abstract

Objective—To compare by BMI percentile group the point prevalence of Metabolic Syndrome (MetS) and its components in adolescents using two definitions of MetS, one including a measure of fasting plasma glucose ($MetS_{IFG}$) and the other an estimate of insulin resistance ($MetS_{HOMA}$).

Design—Cross-sectional analysis.

Setting—Two New York City public high schools, from 2008 through 2011.

Participants—Convenience sample of 1,185 high school students participating in The BODY Project, a medical screening and education program.

Main Outcome Measures—Prevalence of individual MetS components: central adiposity, hypertriglyceridemia, low high-density lipoprotein cholesterol, hypertension, impaired fasting glucose, and insulin resistance using the homeostasis model assessment of insulin resistance (HOMA-IR); and rates of $MetS_{IFG}$ and $MetS_{HOMA}$.

Results—The $MetS_{IFG}$ and $MetS_{HOMA}$ point prevalences were both 0.3% in the healthy weight group and respectively 2.6% and 5.9% ($P < 0.05$) in the overweight group and 22.9% and 35.1% ($P < 0.05$) in the obese group. Only 1.0% of participants had impaired fasting glucose (IFG; glucose levels ≥ 100 mg/dl), whereas HOMA-IR ≥ 3.99 was found in 19.5% of participants.

Conclusion—Elevated HOMA-IR is much more sensitive than IFG to identify adolescents with metabolic dysregulation, and as a result, using a HOMA-IR value ≥ 3.99 identifies more youth as having MetS than using IFG. In addition to increasing the sensitivity of detection of MetS, HOMA-IR has a much higher association to the other MetS components than IFG, and may thus better reflect a unified underlying pathological process useful to identify youth at risk for disease.

INTRODUCTION

The Metabolic Syndrom (MetS) has been clearly defined in adults, but defining MetS in children and adolescents is more challenging due to normal changes in blood pressure, lipid values, and insulin sensitivity that occur during development and that are influenced by sex and ethnicity.[2-5] Furthermore, a lack of large prospective studies capturing the natural

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history of childhood MetS and its progression to adult disease adds to the challenge.[6] To provide continuity with the adult literature, a variety of ageand sex-dependent adjustments of adult MetS definitions have been created, resulting in several definitions of childhood MetS, leading to wide-ranging variability in the reported prevalence.[5] Nevertheless, the prevalence of MetS in adolescence rises with increasing excess weight, tends to be higher among males, and varies by race/ethnicity.[7]

Some investigators have proposed that insulin resistance is the central factor driving the abnormalities observed in MetS.[8-9] Insulin resistance and concurrent fasting hyperinsulinemia short of T2DM are not only independently associated with MetS markers such as high triglycerides, elevations in blood pressure, and low high-density lipoprotein (HDL), [10-12][13] but have also been linked to compromised brachial artery distensibility, [14] hepatic steatosis,[15] and polycystic ovary disease.[16]

Most definitions of MetS use impaired fasting glucose (IFG) as a marker of insulin resistance. However, in insulin resistant youth, fasting blood sugar often remains normal due to compensatory hyperinsulinemia and adequate pancreatic beta-cell reserve.[6, 17-18] As a result, elevated fasting insulin is more common than IFG in adolescent populations.[19] Some researchers have used oral or intravenous glucose tolerance tests (IVGTT) to identify impaired glucose tolerance and to create definitions of MetS.[20-21] These dynamic assessments of insulin function are too invasive or time-consuming to be used in large population studies or in a clinical setting. As a result, the homeostasis model assessment of insulin resistance (HOMA-IR) score, an estimate of insulin resistance incorporating paired fasting insulin and glucose levels, has been suggested as an alternative to an isolated fasting glucose level.[22] HOMA-IR has been validated against both clamps and IVGTT in both healthy weight and overweight youth.[23-25]

Given the long term health consequences of metabolic abnormalities in childhood, we aimed to: 1) determine the prevalence of MetS and its components among healthy weight, overweight, and obese inner city public high school students; 2) compare the prevalence of MetS when using two different definitions: one using IFG and the other using HOMA-IR to define the glucose regulation component; and 3) compare how strongly HOMA-IR and fasting glucose are associated with the other MetS components.

METHODS

Participants and Procedure

The data for this project come from a convenience sample obtained from the Banishing Diabetes in Youth (BODY) Project, a school-based health screening and education program that is part of New York University Langone Medical Center's Community Service Plan, which is described in detail elsewhere.[26] Students from grades 9-12 were recruited from two New York City Public High School campuses with predominantly Hispanic and African American students from low-income households (82% were eligible for and/or enrolled in the free lunch program for which low family income is a pre-requisite). Our team measured the height and weight of all students in each participating school. Body Mass Index (BMI) percentile adjusted for age and sex was calculated using the BMI Calculator for Children and Teens on the Center for Disease Control and Prevention website.[27] Students with a BMI < 85th percentile were classified as healthy weight, those with a BMI ≥ 85th percentile but < 95th percentile were classified as overweight, students ≥ 95th percentile were classified as obese. All students with a BMI ≥ 85th percentile were approached to participate in the medical screening. A comparison group of healthy weight students, one for every two overweight/obese students participating in the project we randomly selected. Eighty-seven percent of students approached for participation assented to participate. Sixty-three percent

of assenters, unless they were over 18 years of age and could sign the consent themselves, returned signed parental consent and participated in the medical screening. Among the students eligible to participate, there were no differences between participants and non-participants on age, BMI, and BMI percentile. Although girls participated in slightly higher numbers than boys, there were no differences in age, BMI, or BMI percentile when participants and non-participants were compared separately by sex.

Participants were asked to arrive at the school-based health center between 7:30 and 8:30am after an overnight 10-12 hour fast. A total of 1592 participants returned signed consents and completed the medical evaluation. We excluded students from the final analyses for the following reasons: 359 participants were excluded because of a systematic error in blood pressure measurement, 1 participant because he had type 1 diabetes, and 30 participants were missing data for one or more MetS component. In addition, 17 participants were excluded because they were likely not fasting; they had “fasting” insulin levels 2.5 standard deviations above the mean of the obese group. Although all bellow 100 mg/dl they also had statistically significant elevations in “fasting” glucose levels, but did not have elevations in hemoglobin A1c (HbA1c) values. After these exclusions, 1,185 participants were included in the final analyses.

The study was approved by the institutional review boards of the New York University School of Medicine, the New York City Department of Education, the New York City Department of Health and Mental Hygiene, and the Nathan Kline Research Institute.

Anthropomorphic measurements

Height, weight, and waist circumference were measured again on the day of the medical evaluation. Height was measured to the nearest 0.1 cm with a Seca 214 Height Rod and weight was measured to the nearest 0.01 kg with a Healthometer 349KLX Digital Remote Display Scale. With the participant in the standing position and wearing a single layer of clothing, waist circumference was measured to the nearest 0.1 cm by placing the tape just superior to their iliac crest as per the CDC Anthropometry Procedures manual. [28]

Blood Pressure Measurements

Blood pressure was measured using a Philips SureSigns VS1 electronic vital signs monitor and a cuff appropriate for the participant’s arm diameter. The first blood pressure measurement was obtained after the participant had been seated for 5 minutes, with a second reading taken within 10 minutes of the first. The lower of the two readings was used in data analyses. Blood pressure percentiles were calculated using EZ-Blood Pressure software [29] based on normative data from the US National Heart, Lung, and Blood Institute’s Task Force Report on High Blood Pressure in Children and Adolescents from 2004 for participants up to 18 years of age. Adult criteria were used for those over 18. Three hundred and fifty-nine participants, who were evaluated before we had properly implemented these blood pressure procedures, had unreliable blood pressure measurements and were excluded from the analyses.

Blood Chemistry Measurements

Fasting blood glucose, collected in fluorinated tubes, was measured using a glucose oxidase method (VITROS 950 AT, Amersham, England) and insulin was assayed using chemiluminescence (Advia Centaur, Bayer Corporation, Bohemia, NY). Total cholesterol, HDL, and triglycerides were analyzed using Vitros chemistry DT slides (Johnson and Johnson Clinical Diagnostics Inc., Rochester, NY). HbA1c was measured using an automated HPLC method (Tosoh Corporation, Kanagawa, Japan) certified by the National Glycohemoglobin Standardization Program. HOMA-IR was calculated as: fasting blood

glucose (mg/dl) × fasting insulin (μIU/mL)/405. [30] High sensitivity C-reactive protein (CRP) levels were measured using an enzymatic immunoassay (Vitros CRP slide, Ortho Clinical Diagnostics).

Definition of Metabolic Syndrome (MetS)

We used two definitions of MetS. The first, published by Ford et al. and used in other studies,[31-33], IFG is the component measuring glucoregulatory control [34]; MetS utilizing this definition will be referred to as $MetS_{IFG}$. An adolescent was considered to have $MetS_{IFG}$ when 3 or more of the following 5 criteria were met:

1. Central adiposity (waist circumference ≥ 90th percentile for age and sex) [4]
2. Hypertriglyceridemia (triglycerides ≥ 110 mg/dl)
3. Low HDL cholesterol (HDL cholesterol ≤ 40 mg/dl)
4. Elevated blood pressure (for children less than or equal to age 18 a systolic or diastolic blood pressure > 90^{th} percentile adjusted for height, age, and sex or ≥130/85, whichever is lower; for those over age 18 ≥130/85) [35]
5. IFG (fasting blood glucose ≥ 100 mg/dl)

In addition, we constructed an alternate MetS definition ($MetS_{HOMA}$), substituting the IFG with an elevated HOMA-IR. As has been previously described in adolescent populations, [36] we used a HOMA-IR ≥ 3.99 as the cut-point for abnormal glucose regulation instead of a fasting blood glucose ≥ 100 mg/dl.

Statistical analysis

Differences in anthropomorphic and metabolic variables were compared across BMI percentile groups using one-way ANOVA with Tukey's HSD test. Prevalence of MetS was compared using a paired sample t-test, where appropriate. Categorical variables were compared using the Cochran-Armitage test for trend. Linear regression analyses were used to establish how well BMI, waist circumference, blood pressure, HDL, triglyceride, and CRP levels could predict either HOMA-IR or fasting glucose levels. Please note that we used the raw data (and adjusted for age, sex, and race/ethnicity), rather than the percentiles, since we had some participants over 18 years of age. For these analyses, the independent variables were BMI, waist circumference, systolic and diastolic blood pressure, HDL, triglyceride, and CRP values. The dependent variables were either HOMA-IR or fasting glucose. With the exception of the Cochran-Armitage test for trend, all analyses were conducted using SPSS version 19. Statistical significance was set at $\alpha = 0.05$.

RESULTS

Demographic and Blood Chemistry Data

After the exclusions 1,185 participants were included in the study sample. Their ages ranged from 14 to 19 inclusive, with an average age of 16.7 ± 1.2 years; 54.6% were female; 74.5% were Hispanic, 17.9% non-Hispanic Black, and 7.6% were other (White or Asian). Participats' characteristics are presented in Table 1. There were significantly fewer females in the obese group than the healthy weight or overweight groups ($P<0.001$). Race/ethnicity did not vary by weight group. As expected, waist circumference, diastolic blood pressure, fasting insulin and HOMA-IR, LDL, HDL, and CRP levels differed significantly across all BMI categories ($P < 0.05$). Participants in the obese group had higher fasting glucose, systolic blood pressure, and triglycerides than either the healthy weight or the overweight students. Participants in the overweight group had HbA1c values lower than either the healthy weight or the obese group.

Furthermore, when we contrasted the 115 participants with BMI's ≥ 99th percentile (average BMI = 39.5 ± 4.6 kg/m^2) with the remaining 339 obese participants that had BMIs ≥ 95th but less than 99th percentile, we found that those with BMI's ≥ 99th percentile had significant elevations in waist circumference and blood pressure, fasting insulin levels, HOMA-IR, CRP, and triglyceride levels, and significantly lower HDL levels relative to the remainder of the obese participants. There was no significant difference in fasting glucose levels between these two obese groups (data not shown in Table 1).

Comparison of Metabolic Syndrome Rates Using the Two Different Definitions

As can be seen in Table 2, in our entire sample 9.5% of participants met criteria for MetS using IFG ($MetS_{IFG}$) and 15.1% met criteria when HOMA-IR ≥ 3.99 was substituted for fasting glucose ($MetS_{HOMA}$). $MetS_{HOMA}$ consistently identified more participants with MetS than $MetS_{IFG}$. One healthy weight female met criteria for $MetS_{IFG}$ as well as $MetS_{HOMA}$. Regardless of the definition used, males tended to have higher rates of MetS than females and MetS point prevalence increased with BMI.

Point Prevalence of Metabolic Syndrome Components

As can be seen in Table 3, there was a trend toward higher prevalence of all MetS components with increasing BMI percentile. In the healthy weight group, low HDL was the most common abnormality observed. Central adiposity was the most commonly observed abnormality in the obese group. IFG was present much less frequently than IR. Four and one half percent of healthy weight, and 12.4% of overweight, and 37.8 % of obese participants had a HOMA-IR ≥ 3.99 (P = 0.001). Although there were no clinically-relevant differences in the percent of participants with IFG across the three weight categories (0.6% of healthy weight, 0.3% of overweight, and 2.0 % of obese), because of the large number of subjects these very small differences reached statistical significance in the trend analyses (P = 0.03).

How well do BMI, waist circumference, HDL, triglycerides, and blood pressure, and CRP predict HOMA-IR and fasting glucose?

Utilizing linear regression analysis, and after adjusting for age, race/ethnicity, and sex (R^2 =0.020), all other MetS components and CRP were significant predictors of HOMA-IR and all but HDL (a trend, P = 0.061) predicted fasting glucose levels. However, as can be seen in Table 4 the total variance (adjusted R^2) explained by all other variables, was consistently higher (ranging from 2- to 5-fold larger) in the predictions of HOMA-IR than that of fasting glucose level.

DISCUSSION

We demonstrate that in a sample of predominantly Hispanic inner-city high school students, obesity is linked to a host of metabolic abnormalities. As also noted by other investigators, [20-21, 37-39] we found that increasing BMI, was not only related to a larger waist circumference, but associated with increases in blood pressure, abnormalities in the lipid profile, higher fasting insulin levels, and higher levels of CRP. In our sample MetS prevalence also increased with increasing BMI. Healthy weight appeared to be protective of MetS, with only 1 (0.3%) healthy weight adolescent meeting criteria for $MetS_{HOMA}$. This is in agreement with Cook and colleagues (2008), who described the prevalence of MetS among normal weight adolescents to be 0-1.6%.[31]

MetS is a useful clinical and research construct for identifying Individuals at increased risk of T2DM, CVD, and osteoarthritis,[40] among other chronic illnesses.[41-42] In children, a MetS diagnosis can be a particularly valuable catalyst for an intensive diet and exercise intervention targeted at preventing further disease progression.[43] However, our work

highlights that a definition of MetS, which utilizes IFG, may fail to identify children with significant insulin resistance and hyperinsulinemia. Children can mount compensatory insulin secretion to remain normoglycemic, while displaying evidence of significant insulin resistance, and thus remain at increased risk of developing numerous chronic conditions later in life.[14] In our sample of over 1,000 adolescents we found marked differences in the prevalence of IFG relative to that of HOMA-IR ≥ 3.99 by BMI percentile categories. IFG was present in only 2.0% of our obese participants. Alternatively, using a conservative HOMA-IR cutpoint of ≥ 3.99 as an estimate of insulin resistance,[22, 37] 37.8% of our obese adolescents fulfilled this criterion (Table 3). The increased prevalence of elevated HOMA-IR scores relative to IFG has been also described by others. For example, Cook et al. analyzing data from 12-19 year olds from NHANES '99-'02, found that 8.6%, 15.4%, and 16.5% of normal, overweight, and obese children respectively had a fasting blood sugar of over 100 mg/dl.[31] Meanwhile using the data from the same NHANES surveys, Lee reported that roughly 9%, 20% and 60% of normal, overweight, and obese children had a HOMAIR greater than or equal to 3.99.[37] Using similar data, Li and colleagues found that 13.1% of the population in a nationally representative sample of 12-19 year olds had a fasting glucose above 100 mg/dl, while 37.1% had hyperinsulinemia (fasting insulin above 13.8 μIU/mL).[44] Although our data are consistent with nationally representative data in demonstrating that elevated HOMA-IR scores and hyperinsulinemia are more common among adolescents than IFG, our point prevalence of IFG is lower than in similar school-based studies as well as nationally representative studies. For the measurement of glucose levels, samples were collected in tubes containing intended to prevent red cells from metabolizing glucose and thus artificially reducing glucose level prior to measurement. Nevertheless, given that there was approximately a 3 hour delay in this study between the blood sample being drawn and the assay being performed, it is possible that our low prevalence of hyperglycemia is the result of a systematic underestimation of glucose values due to our measurement procedure.[45]

While MetS components and CRP were significantly associated with both fasting blood glucose and HOMA-IR, they systematically accounted for 2 to 5-fold higher variance in HOMA-IR than in fasting glucose level (Table 4). This is likely due to the causal role that has been attributed to both insulin resistance and hyperinsulinemia in the development and progression of hypertension and the dyslipidemic components of MetS. Our work agrees with Sharma and colleagues (2011),[22] who suggested that the incorporation of HOMA-IR into a pediatric MetS definition creates a more consistent construct that is more likely to reflect a cohesive underlying physiology than a MetS definition that utilizes the IFG adult standard.

Although the average age of our participants was 16.7 ± 1.2 years, we did not ascertain sexual development stage, and there is the possibility that some of our participating students were pre-pubertal. Insulin resistance increases during early teenage years until sexual development Tanner stage 3 and eventually normalizes by the completion of puberty.[2, 46-47] However, Lee and colleagues (2006) noted that in a nationally representative sample of US adolescents, HOMA-IR scores demonstrated limited variability by age in normal and overweight adolescents and high variability in obese adolescents.[36] Moreover, insulin resistance also varies by sex and ethnicity,[48] therefore future work should determine appropriate age, sex, and ethnicity cut-offs for estimates of insulin resistance.[49]

While IFG is a significant risk factor for a host of diseases,[50] IFG represents an abnormality further along in the progression of obesity to T2DM and likely reflects concurrent insulin resistance and beta cell insufficiency, which occurs after insulin resistance has already been established.[51] Reduced insulin sensitivity, resulting in compensatory fasting hyperinsulinemia, even in the presence of normal fasting glucose

levels, also poses serious health risks and has been implicated in the development of precursors of CVD, T2DM, hypertension, dyslipidemia, hepatic steatosis, polycystic ovary syndrome, and inflammation in the pediatric population.[6] Given that a primary purpose of the MetS construct is to identify children and youth at risk for diabetes and CVD as early as possible, using a definition of MetS which includes HOMA-IR provides a greater opportunity for interventions intended to halt or reverse progression of MetS to more advanced disease.

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Table 1

Characteristics of Students With Complete Medical and Anthropomorphic Data Unless otherwise indicated, data are expressed as mean (SD).

Characteristics	Healthy Weight (n=356)	Overweight (n=387)	Obese (n=442)
Sex (% Female)	57.3 [b]	61.5 [b]	46.4
Race/Ethnicity			
Hispanic/Latino %	74.7	74.2	74.7
Black/African American %	18.5	17.8	17.4
Other/unknown %	6.7	8.0	7.9
Age years	16.9 (1.2) [b,c]	16.7 (1.3)	16.6 (1.2)
BMI kg/m^2 [a]	21.9 (2.2)	26.6 (1.5)	33.8 (4.6)
Waist circumference cm [a]	75.2 (8.4)	85.7 (6.6)	102.3 (11.7)
Systolic blood pressure mmHg	114.4 (9.3) [b]	115.8 (9.9) [b]	121.8 (11.5)
Diastolic blood pressure mmHg [a]	64.0 (7.7)	69.4 (9.3)	73.0 (10.4)
Fasting glucose mg/dL	79.2 (7.0) [b]	79.4 (6.6) [b]	81.4 (7.6)
Fasting insulin μIU/mL [a]	10.0 (5.7)	12.0 (6.7)	18.6 (9.3)
HOMA-IR [a]	2.0 (1.3)	2.3 (1.4)	3.8 (2.0)
HbA1c (%)	5.43 (0.31) [c]	5.35 (0.33)	5.40 (0.35)
LDL mg/dL [a]	85.4 (22.0)	92.0 (24.6)	98.0 (24.9)
HDL mg/dL [a]	52.5 (11.1)	48.4 (10.9)	43.4 (9.1)
Triglycerides mg/dL	66.2 (24.9) [b]	73.4 (45.7) [b]	90.6 (64.3)
C-reactive protein (CRP) mg/L [a]	0.9 (1.4)	1.4 (2.1)	3.1 (3.2)

[a] Indicates significant differences (P<0.05) among all BMI percentile groups

[b] Indicates significantly different (P<0.05) than the obese group

[c] Indicates significantly different (P<0.05) than the overweight group

Table 2

Comparison of Prevalence $MetS_{HOMA}$ and Met_{SIFG} by Gender and Weight Group

	$MetS_{HOMA}$			$MetS_{IFG}$		
	Male (n=538)	**Female (n=647)**	**Total (n=1185)**	**Male (n=538)**	**Female (n=647)**	**Total (n=1185)**
Total (%)[a]	94 (7.5%)	85 (13.1%)	179 (15.1%)	66 (12.3%)	46 (7.1%)	112 (9.5%)
Healthy Weight (%)	0 (0%)	1 (1.5%)	1 (0.3%)	0 (0%)	1 (0.5%)	1 (0.3%)
Overweight (%)[a]	9 (6.0%)	14 (5.9%)	23 (5.9%)	4 (2.7%)	6 (2.5%)	10 (2.6%)
Obese (%)[a]	85 (35.9%)	70 (34.1%)	155 (35.1%)	62 (26.2%)	39 (19.0%)	101 (22.9%)

[a]Indicates significant differences in prevalence between $MetS_{HOMA}$ and $MetS_{IFG}$ for total and gender groups separately.

Table 3

Prevalence of MetS components by sex and BMI percentile group (n=1185).

MetS Component	Healthy Weight	Overweight	Obese	*P* Value
High Blood Pressure, %	11.8	25.6	30.3	<0.001
High Triglycerides, %	6.7	13.2	23.3	<0.001
Low HDL, %	13.2	23.8	38.9	<0.001
Central Adiposity, %	2.2	23.8	72.6	<0.001
Insulin Resistance, %	4.5	12.4	37.8	<0.001
IFG, %	0.6	0.3	2.0	0.030

Table 4

Linear Regression Analyses Demonstrating the Ability of Various Metabolic and Anthropomorphic Variables to Predict HOMA and Fasting Glucose *

	HOMA-IR			Fasting Glucose		
Dependent Variables	**β**	**Adujsted R^2**	***P* Value**	**β**	**Adjusted R^2**	***P* Value**
BMI, kg/m^2	0.488	**0.256**	<0.001	0.159	**0.057**	<0.001
Systolic BP, mmHg	0.301	**0.099**	<0.001	0.166	**0.056**	<0.001
Diastolic BP mmHg	0.199	**0.056**	<0.001	0.067	**0.036**	0.019
Waist Circ, cm	0.498	**0.263**	<0.001	0.171	**0.060**	<0.001
Triglycerides, mg/dl	0.336	**0.128**	<0.001	0.107	**0.043**	<0.001
HDL, mg/dl	−0.223	**0.064**	**<0.001**	−0.055	**0.034**	0.061
CRP, mg/dl	0.326	**0.122**	<0.001	0.154	**0.052**	<0.001

* All analyses were adjusted for age, sex and race/ethnicity (Adj R^2 = 0.020) *P* values indicate significant differences in MetS component prevalence according to weight category