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**Abstract**

Metabolic syndrome is a collection of risk factors that increase the risk for cardiovascular disease. The objective of this study was to determine which of the following potential risk factors were significantly different between normal-weight and overweight children. Potential risk factors included: fasting blood glucose, blood glucose after consumption of food, the amount and type of food and beverage selected, blood pressure, height and weight (to calculate BMI), heart rate during inhalation and heart rate during exhalation, and fungiform papillae density. Those measures which showed significant differences between the normal-weight and overweight children should be included in the pediatric definition of metabolic syndrome in children. The results indicated that BMI, fasting blood glucose, and blood pressure are important risk factors in metabolic syndrome. Future studies could include triglycerides, cholesterol, and physical fitness as potential risk factors. Furthermore, additional studies should be conducted on taste receptor density as well as food selection in relation to metabolic syndrome.

**Introduction**

Metabolic syndrome is defined as a collection of risk factors that increase the risk for cardiovascular disease (CVD) (Grundy et al., 2004). According to Reaven (1988), people with CVD usually have a clustering of risk factors including obesity, atherogenic dyslipidemia, elevated blood pressure, insulin resistance and/or glucose intolerance, a proinflammatory state, and a prothrombotic state. Reaven called this syndrome X, but the name was changed to insulin resistance syndrome and later to metabolic syndrome to avoid the implication that insulin was solely responsible for the syndrome (Grundy et al., 2004).

*Obesity as a Risk Factor for Metabolic Syndrome*

Obesity is one of the main risk factors of metabolic syndrome (Grundy et al., 2004). It is the increase of body weight due to excessive accumulation of fat, usually measured by body mass index (BMI). BMI is an indicator of the weight-to-height ratio and is defined by the formula \[ \text{BMI} = \frac{\text{body weight (kg)}}{\text{height(m)}^2} \]. Cutoff points have been established for BMI: less than 18.5 is considered underweight; between 18.5 and 24.99 is considered normal weight; greater
than or equal to 25 is considered overweight; and greater than or equal to 30 is considered obese (World Health Organization, 2010).

There are three modes of fat accumulation (McGill, 2008). The first mode is pure energy overload, which involves consuming more calories than are being expended. The second mode of fat accumulation is nutritional imbalance, usually a lack of co-factors for efficient fat oxidation. The third mode is associated with the effect of stress hormones (McGill, 2008).

Abdominal obesity, also known as central obesity, is the main form of obesity associated with metabolic syndrome (Grundy et al. 2004). Abdominal obesity is clinically recognized by an increase in waist circumference or an increase in waist-to-hip ratio. Ideally, the waist: hip ratio should be less than or equal to 0.8 for women and less than or equal to 0.95 for men (Collins, 2007). One of the main causes of the recent spike in diagnoses of the metabolic syndrome in the United States is the obesity epidemic (Chobanian et al., 2003).

*Atherogenic Dyslipidemia as a Risk Factor for Metabolic Syndrome*

Atherogenic dyslipidemia is a condition in which the artery wall thickens as the result of a build-up of fatty materials due to a disruption of the amount of lipids in the blood (Grundy et al., 2004). Atherogenic dyslipidemia is characterized by elevated triglycerides and low concentrations of HDL cholesterol. A more in-depth analysis reveals increased remnant lipoproteins, elevated apolipoprotein B and small LDL cholesterol particles. Atherogenic dyslipidemia results in inflammation and can lead to cardiovascular disease (Grundy et al., 2004).

*Elevated Blood Pressure as a Risk Factor for Metabolic Syndrome*

Elevated blood pressure, or hypertension, is strongly associated with obesity and also commonly occurs in insulin-resistant people. It is believed by some investigators to be less
metabolic than other factors of the syndrome, but it is almost universally included in the syndrome definition. Blood pressure is the measure of the force of the blood on the walls of the arteries (Dugdale et al., 2009). Factors that determine this pressure are the amount of blood being pumped by the heart, the force that the heart is pumping, and the size and flexibility of the arteries. Blood pressure is measured with a stethoscope and a sphygmomanometer, commonly called the blood pressure cuff. Inflating the cuff to about 180 mmHg will cause all of the blood vessels to collapse. Slowly releasing air out of the cuff will allow the blood to rush back into the vessels, giving what is called the systolic blood pressure, or the maximum pressure exerted when the heart contracts. As the air is released from the cuff, eventually, there will be no sound heard in the stethoscope, and this is the diastolic blood pressure, or the minimum pressure in the arteries when the heart is at rest. A normal blood pressure is 120/80 mmHg (systolic/diastolic), hypertension is defined as 140/90 mmHg or greater (Dugdale et al., 2009). Hypertension has been shown to be linked to cardiovascular disease, and longitudinal studies have shown a more than two-fold increase in risk from CVD for those with blood pressure in the range of 130-139/85-89 mmHg compared to those with blood pressure less than 120/80 mmHg (Chobanian et al., 2003).

*Insulin Resistance as a Risk Factor for Metabolic Syndrome*

Insulin is produced by the pancreas and aids in the movement of glucose across the cell membrane in fat and muscle cells (Baumann et al., 2000). Insulin resistance occurs when people become insensitive to their own insulin (Grundy et al., 2004). Individuals with chronic insulin resistance tend to develop glucose intolerance, which can lead to hyperglycemia, and eventually, if the blood sugar reaches a high enough concentration, type 2 diabetes (Grundy et al., 2004).
Insulin resistance is strongly associated with CVD. Adiponectin is an adipokine secreted by the white adipose tissue (Kadowaki, 2008). Adiponectin has been shown to affect insulin sensitivity through modulation of insulin signaling pathway. There are two adiponectin receptors, adiponectin receptor 1 (found throughout the body) and adiponectin receptor 2 (found mainly in the liver). These receptors are both integral membrane proteins, with their n-terminus on the interior of the cell and the c-terminus on the exterior of the cell, which is the opposite orientation of all other G-protein coupled receptors. Increased fat accumulation in obesity results in decreased adiponectin secretion (Kadowaki, 2008).

Leptin is a protein that is also produced by the adipose tissue (Haynes, 2000). Leptin and adiponectin act in an antagonist fashion in a feedback loop with the hypothalamus to regulate food intake, maintain an adequate fat reserve, and maintain energy homeostasis (Haynes, 2000; Kadowaki, 2008). When adiposity shrinks, the leptin signal decreases and the adiponectin signal increases, which suppresses energy expenditure and promotes fat storage. When adiposity rises, the leptin signal is increased and the adiponectin signal is decreased which increases energy expenditure and inhibits fat storage. If this balance is disturbed in any way, obesity can develop (Haynes, 2000; Kadowaki, 2008).

Proinflammatory and Prothrombotic States as Risk Factors for Metabolic Syndrome

A proinflammatory state is a condition that supports inflammation in the body (Grundy et al., 2004). It is clinically diagnosed by elevated C-reactive protein. Multiple mechanisms are responsible for this increase in C-reactive protein, one of which is obesity. Excess adipose tissue releases inflammatory cytokines that raise C-reactive protein levels. A prothrombotic state is a condition that supports the formation of a blood clot. It is clinically recognized by an increase in plasma plasminogen activator inhibitor as well as fibrinogen. Fibrinogen is an acute-phase
reactant like C-reactive protein, so it is also increased by the release of cytokines. This shows that the proinflammatory state and the prothrombotic state are related (Grundy et al., 2004).

C-reactive protein (CRP) is produced by the body in response to injury or infection (Lambert, 2004). It is also a risk factor for type 2 diabetes; adult studies have shown that as CRP levels rise, the development of diabetes and CVD also increases. CRP is linked to most of the components of the metabolic syndrome including: body fat, blood pressure, insulin, triglycerides, and cholesterol. The link between CRP and BMI can be explained by the molecule interleukin-6, which is a primary determinate of CRP production in the liver. Interleukin-6 is a type of cytokine that is released from subcutaneous adipose tissue. The amount of interleukin-6 released is directly proportional to the amount of fat present, so the more fat a person has accumulated, the more interleukin-6 released, and the more CRP that is produced by the liver (Lambert, 2004).

*Correlates of Metabolic Syndrome in Adults*

In adults, it is known that abdominal obesity is positively correlated to metabolic syndrome. There are many suggested mechanisms behind this, one of which is that abdominal adipose tissue has an increased amount of catecholamine-induced lipolysis primarily due to an increase in adipocyte B-adrenergic receptor function (Kelley et al., 2000). This lipolysis releases an abnormally high amount of free fatty acids into the circulatory system and causes the build-up of lipids in sites such as the muscle and liver. Elevated free fatty acid flow into the liver inhibits insulin binding and degradation, which leads to insulin resistance and dyslipidemia (Grundy et al., 2005, Wajchenberg 2000). The abdominal adipose tissue also increases production of inflammatory cytokines, plasminogen activator inhibitor-1, and other bioactive products while simultaneously reducing the amount of adiponectin that is produced. This also explains the connection between obesity and a proinflammatory state (Grundy et al., 2005).
Hypertension is another correlate of metabolic syndrome in adults (Plans et al., 1993). There are multiple known causes of hypertension. Hypertension has been shown to be associated with hypercholesterolemia. This association could be explained by five possible mechanisms. The first possible mechanism is that both are related to arteriosclerosis, which is associated with an increased vascular compliance. The second possible mechanism is that hypercholesterolemia is associated with impaired endothelium-dependent vascular relaxation. The third possible mechanism is that increased sympathetic nervous activity leads to hypertension and dyslipidemia. The fourth possible mechanism is that diets high in fat and cholesterol may lead to prostaglandin metabolism dysfunction. The fifth and final mechanism is hyperinsulinemia secondary to peripheral insulin resistance is a mechanism linking hypertension, diabetes, obesity and dyslipidemia (Plans et al., 1993)

Another correlate of metabolic syndrome in adults is serum cholesterol. HDL cholesterol is considered the “good” cholesterol, and it makes up about 20% of the total plasma cholesterol (Stein et al., 1999). There is an inverse correlation between HDL cholesterol and CVD, which suggests that elevated HDL shields against CVD. A proposed mechanism for this is that plasma HDL carries cholesterol from the peripheral tissues to the liver where it is catabolized and excreted. So, higher levels of HDL cholesterol are associated with less atherosclerosis (Grover et al., 2003). LDL cholesterol is considered the “bad” cholesterol, and it makes up the other 80% of total plasma cholesterol. Dysfunction of the normal processes carried out by the endothelium is a necessary occurrence in the pathogenesis of atherosclerosis (Stein et al., 1999). Although there are many causes of endothelial dysfunction, oxidized LDL cholesterol is toxic to endothelial cells and plays a considerable role in the instigation and continuation of
atherogenesis and therefore atherogenic dyslipidemia and the metabolic syndrome (Stein et al., 1999).

Increased physical activity is shown to have a positive correlation in weight reduction, and physical activity also has beneficial effects on the metabolic risk factors of metabolic syndrome (Grundy et al., 2005). Leisure Time Physical Activity (LTPA) is measured in metabolic equivalents; it is the physical activity that people do in their spare time (Laaksonen, 2002). Low level LTPA would be walking, yard work, and hunting or fishing; moderate LTPA would be brisk walking, swimming, biking and chopping wood; and vigorous LTPA would be skiing, jogging, and playing ball sports. Moderate and vigorous LTPA decreased the risk of metabolic syndrome by nearly two-thirds. Low-intensity leisure time physical activity also decreased the likelihood of developing metabolic syndrome, although not as radically as the higher intensities. For those with a sedentary lifestyle, doing 60 minutes of moderate or vigorous LTPA may not be within their physical capabilities; however, performing 60 minutes of low intensity activity may be successfully achieved simply by adapting a more active lifestyle.

Getting some form of physical activity in people with a sedentary lifestyle is very important, since men in Laaksonen’s (2002) sedentary group were seven times more likely to develop metabolic syndrome than fit men. Even active but unfit men were still 2.5 times more likely to develop the syndrome than to fit men. One way to measure cardiovascular fitness is by measuring the $V_{02}\text{max}$, which is the point at which “no further increases in O$_2$ intake can occur, the heart, lungs, circulation, and the diffusion of oxygen to the active muscle-fibers have attained their maximum activity” (Billat and Koralsztein, 1996 p. 91). Measurement of the $V_{02}\text{max}$ may be a good indicator of people who need more intensive intervention to prevent the future development of metabolic syndrome (Laaksonen, 2002).
There is a process linking depressive symptoms with the metabolic syndrome that goes in both directions and begins early in life, mostly likely in childhood (Pulkki-Raback, 2009). High depressive symptoms in adulthood were found to predict increased risk for the metabolic syndrome in women, and metabolic syndrome in childhood predicted depressive symptoms later in life. A large part of the associations between depressive symptoms and the metabolic syndrome was attributable to central obesity. Stress hormones involved in depression, including epinephrine, norepinephrine, and cortisol, contribute to increased central adiposity and increased sympathetic tone which in turn has been suggested to be one of the main mechanisms in the development of insulin resistance and cardiovascular diseases (Pulkki-Raback, 2009).

**Metabolic Syndrome in Children**

Metabolic syndrome is becoming more and more prevalent in the pediatric population (Rizzo et al., 2008). Most children who develop the metabolic syndrome will live with the symptoms for the majority of their lives. This prolonged medical condition will not only affect their health, but the economy as well. In USA in 1995 the total expenses attributed to obesity alone were estimated at almost 100 billion dollars (Lev-Ran, 2001). So this research is very important to the health of people with metabolic syndrome and to reducing the cost to our already struggling health care system and economy.

In a study by Lambert et al. (2004), the authors examined a population of adolescents aged 9, 13 and 16 years. Since there is no standard definition of metabolic syndrome in children, most of the studies use a statistical approach and define cut points relative to a selected percentile of a reference population based on age, sex and race-ethnicity. This approach makes it difficult to compare results between studies since the absolute values of these cut points differ in different populations. The objectives of Lambert et al.’s (2004) study were to figure out the prevalence of
metabolic syndrome and test the independent effects of insulin resistance and adiposity, as well as indentify the underlying components of metabolic syndrome, and to see if there was any correlation between adiposity and free fatty acids. The authors did this by measuring the subjects’ height, weight, and blood pressure and performing a skin-fold test. They also obtained a fasting blood sample, from which they got data on the levels of insulin, blood glucose, lipids, cholesterol and free fatty acids (Lambert et al., 2004).

Lambert et al. (2004) found that about 11.5% of their young subjects studied had metabolic syndrome. Mean values of systolic blood pressure, diastolic blood pressure, blood glucose and triglycerides increased significantly across insulin quartiles in all age and sex groups, and HDL cholesterol decreased in all age and sex groups except 16-year-old boys. After adjustment for BMI, insulin was only weakly associated with the clustering of risk factors. After adjustment for insulin, BMI was still strongly associated with the clustering of risk factors, indicating that the independent effect of adiposity is stronger than insulin. During factor analysis, three underlying factors emerged. The first is the lipid factor, which is characterized by positive correlations with BMI, insulin, and triglycerides and a negative correlation with HDL cholesterol. The second factor is the glucose factor which is characterized by positive correlations with BMI, insulin, and glucose. The third is the blood pressure factor, which is characterized by positive correlations with systolic and diastolic blood pressure. The authors also found no overall association with BMI and free fatty acids. This study shows that there is more than one mechanism operating in the pathophysiology of metabolic syndrome and that these mechanisms are operable at a very young age (Lambert et al., 2004).

The prevalence of metabolic syndrome in children increases with the severity of obesity (Weiss et al., 2004). In severely obese children and adolescents, 50% have metabolic syndrome.
Obese adults who had also been obese as children have a higher risk of developing the metabolic syndrome than obese adults who had not been obese as children, which shows that obesity developed in childhood is more destructive than obesity developed in adulthood (Vanhala et al., 1998). A possible mechanism for this is that chronic obesity from childhood into adulthood acts like a “generator” for extended insulin resistance, which leads to the clustering of high blood pressure and other metabolic abnormalities of the metabolic syndrome (Vanhala et al., 1998). Hypertension, in turn, leads to the development of target organ damage as well as the metabolic syndrome (Chobanian et al., 2003). The prevalence of metabolic syndrome in children also increases with insulin resistance.

As seen in adults, physical fitness also has an effect on the pathogenesis of metabolic syndrome in children and adolescents (Eisenmann et al., 2007). Normal weight children who have a high fitness level possess the best overall insulin sensitivity profile. Obese or overweight children who are unfit possess the worst. Within BMI categories (normal weight, over weight, or obese groups), increased fitness correlates with decreased insulin resistance. It is also interesting to note that overweight or obese children with high fitness level possessed similar profiles to normal weight unfit children (Eisenmann et al., 2007).

Age is inversely correlated to LDL cholesterol in normal-weight children (Pinhas-Hamiel et al., 2007). However, the same trend did not occur in the obese population as expected. Insulin resistance in obese children as expressed by HOMA (homeostasis model assessment) was higher than that reported in normal-weight children. In the pediatric obese population, the combination of elevated triglycerides and LDL cholesterol and low HDL cholesterol places them at a greater cardiovascular risk than their normal weight peers, even when the changing patterns of lipids and lipoproteins seen during puberty are accounted for. The pathogenesis of
dyslipidemia of obesity in children seems to be closely related to insulin resistance in obese individuals (Pinhas-Hamiel et al., 2007). Also similar to adults, C-reactive protein and interleukin-6 levels are also positively correlated with increasing obesity in children, and adiponectin levels decrease with increasing obesity (Weiss et al., 2004). This once again demonstrates that the pathophysiological mechanisms related to the metabolic syndrome in adults are already present and fully functional in children.

In a study of obese children in a Therapeutic Lifestyle Change program, insulin resistance and parental obesity both were correlated with poorer weight-loss response (Pinhas-Hamiel et al., 2008). The authors hypothesized that parental obesity would lead to an increase in weight loss, because the parents would be more motivated to take serious measures to prevent their children from suffering the same fate. However, the opposite actually occurred; the children with obese parents actually did not lose as much weight as the children with normal-weight parents. This could be due to the genetic components of the metabolic syndrome, as well as the environmental factors. If the parents have the genetic make-up for obesity, it is very likely that they would pass it on to their offspring. Similarly, if the parents are in an environment that supports obesity, then it is likely that their children are in the same environment. Also, it was discovered that insulin resistance was correlated with a decrease in weight loss. Since treatment for obesity is often not effective, obtaining a measurement of the patient’s insulin resistance and looking at the health of their parents may lead to better designed weight loss programs with higher success rates and generally improved health of society (Pinhas-Hamiel et al., 2008).

Since the 1970’s the frequency of childhood obesity has more than doubled for preschool children aged 2-5 years and adolescents aged 12-19 years, and it has more than tripled for children aged 6-11 years (Institute of Medicine, 2005). Nine million children over the age of six
years are already considered obese (Institute of Medicine, 2005). There is no one definition of metabolic syndrome in children so investigators who study this subject must develop their own, usually by modifying an adult description. However, this leads to a multitude of diverse definitions and makes it difficult to compare the results of different studies. In a study conducted by Golley et al. (2006), four different definitions of metabolic syndrome in children were used, and separate results recorded for each one. The results varied drastically depending on which classification was used. In another study done by Pulkki-Raback et al. (2009), three definitions of metabolic syndrome were used; however, findings were consistent regardless of which definition was used. Clearly, there is a necessity to develop a single universal definition of metabolic syndrome in order to make progress in studying this phenomenon.

Studying and understanding metabolic syndrome in children is necessary in preventing children from developing cardiovascular disease and diabetes, either as adolescents or as later in life as adults. In the United States, the exact prevalence of type 2 diabetes in children is unknown. The National Health and Nutrition Examination Study (1999-2002) estimates that approximately 39,000 12-19 year olds have type 2 diabetes, which is extremely alarming since traditionally this was exceptionally rare in children (Eisenmann et al., 2007). Wilson’s (2008) research has suggested overweight children who chronically overeat may develop hyperinsulinemia, which leads to type 2 diabetes.

Of the four definitions for metabolic syndrome in children used by Golley et al. (2006) two included fasting insulin, and all four included gender and height and BMI, although the cut points for BMI varied with all the definitions. I planned to measure fasting blood glucose, blood glucose after consumption of food, the amount and type of food and beverage selected, blood pressure, height and weight (to calculate BMI), heart rate, and fungiform papillae density to
determine which distinguish normal-weight from overweight children. Those measures which show significant difference between the normal-weight and overweight children should be included in the definition of metabolic syndrome.

**Methods**

**Subjects**

Fifty-eight subjects ages 8-11 were recruited for this study through a letter that was sent out to local elementary schools in Springfield, Ohio, including: Lagonda Elementary, Snow Hill Elementary, Fulton Elementary, Kenton Elementary, and Snyder Park Elementary. Of the 58 subjects who participated in the study, 55 produced usable data. The 55 subjects consisted of 25 girls and 30 boys. Each child received $20 compensation for their participation in the study.

**Procedure**

When the subjects and their parents or guardians arrived at the study, the parents/guardians signed an informed consent form, and the children also signed to give assent to participate. Participants were asked to come to the lunch-time study in a fasting state (no food consumed for three hours prior to the study), and a fasting blood glucose measurement was taken at the outset of the session. Subjects were then invited to eat their choice of Domino’s cheese or pepperoni pizza and drink their choice of bottled water, Motts apple juice, Sprite or Coca-Cola. Fifteen minutes after the subjects started eating, another blood glucose measurement (referred to as post-prandial blood glucose) was taken. Once the subjects had eaten and drunk as much as they wanted, their height, weight, blood pressure, and heart rate were measured. Heart rate measurements were obtained with a polygraphic recorder (Lafayette Instruments, West Lafayette, IN). Unusual blood pressure or blood glucose measurements were reported to the parents.
The participants’ tongues were also tinted blue with blue food coloring (FD&C Blue 1, McCormick & Co., Inc., Hunt Valley, MD) to allow the subjects’ fungiform papillae to be visible. The tongues were photographed next to a ruler, in order to obtain a correct 8mm-diameter circle to scale. The circle template was then placed on four different areas of the tongue, two on each side, the fungiform papillae inside the template were counted inside each sample circle, and the mean number of papillae/50mm² was calculated.

Independent-samples t-tests were conducted to compare known and potential risk factors for metabolic syndrome in my sample of overweight and normal-weight children. Risk factors examined included age, fasting blood glucose, post-prandial blood glucose, taste-receptor density, amount of pizza consumed, height, systolic and diastolic blood pressure, heart rate on inhalation and exhalation, and BMI. The data were then analyzed with Pearson correlation analyses, and a principal components factor analysis was also conducted using varimax rotation.

**Results**

T-test comparisons were made between overweight and normal-weight children. Their mean measures on all examined risk factors are shown in Table 1. Fasting blood glucose was significantly higher for overweight than normal-weight children ($t = 2.11, p = .04$). In addition, a significant difference was also found for height ($t = 3.04, p = 0.004$) with overweight children being taller. A marginally significant difference between overweight and normal-weight children was found for systolic blood pressure ($t = 1.98, p = 0.053$). A series of Pearson correlations analyses were then conducted to assess associations between potential risk factors for metabolic syndrome in children.

**BMI**
A significant correlation was obtained between BMI and fungiform papillae density ($r = 0.375, p = 0.038$). This indicates that children with a larger BMI had significantly higher fungiform papillae density. Furthermore, a significant correlation was found between BMI and age ($r = 0.271, p = 0.048$), showing that older children had significantly higher BMIs. Also, Table 1. Means of Potential Risk Factors for Overweight and Normal-Weight Subjects

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</tbody>
</table>

BMI and fasting blood glucose were found to be significantly related ($r = 0.377, p = 0.005$), which indicates that children with a higher BMI had a higher fasting blood glucose measurement. However, there was not a significant correlation between BMI and post-prandial blood glucose. Finally, BMI and systolic blood pressure were significantly correlated ($r = 0.405, p = 0.002$); this indicates that children with a higher BMI had a higher systolic blood pressure.
Blood Glucose

A significant correlation was obtained between fasting blood glucose and age ($r = 0.333$, $p = 0.016$). This indicates that older children have higher fasting blood glucose. As previously stated, fasting blood glucose was also significantly related to BMI ($r = 0.377$, $p = 0.005$). However, no significantly correlated were found between post-prandial blood glucose and any other measure.

Blood Pressure

Systolic blood pressure was found to be significantly correlated with BMI ($r = 0.405$, $p = 0.002$) as previously stated. In addition, systolic blood pressure was found to be significantly associated with age ($r = 0.561$, $p < 0.001$), indicating that older children have higher systolic blood pressure. Similarly, diastolic blood pressure was significantly correlated with age ($r = 0.273$, $p = 0.046$), which shows that older children also have higher diastolic blood pressure.

Heart Rate

Heart rate measurements were obtained during inhalation and exhalation. Heart rate during inhalation was not found to be significantly associated with any other measures except for heart rate during exhalation ($r = 0.551$, $p < 0.001$). Likewise, heart rate during exhalation was not significantly correlated with any other measure, except heart rate during inhalation.

Food Intake

Children who ate pepperoni pizza avoided cheese pizza, and vice versa ($r = -0.438$, $p = 0.001$). However, no measure of food intake was significantly correlated with BMI, blood glucose, blood pressure, heart rate, age, or fungiform papillae density.

Age

Age was significantly correlated with many measures, including a) fasting blood glucose ($r$...
=0.333, \( p = 0.016 \), b) systolic blood pressure \( (r = 0.561, p < 0.001) \), c) diastolic blood pressure \( (r = 0.273, p = 0.046) \), and d) BMI \( (r = 0.271, p = 0.048) \).

**Fungiform Papillae**

Fungiform papillae density was found to be significantly correlated with BMI \( (r = 0.375, p = 0.038) \) indicating that children with a higher BMI have a significantly greater density of taste receptors on their tongues. Papillae density was not significantly related to any other measure.

**Factor Analysis**

A principal-components factor analysis was conducted using varimax rotation, which split the data into five significant factors with Eigenvalues over 1.0 (see Table 2). Factor 1

**Table 2. Factor Analysis with Factors That Have Eigenvalues over 1.00**

<table>
<thead>
<tr>
<th>Potential Risk Factors</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Factor 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Papillae Density (taste receptors/50mm(^2))</td>
<td>-0.130</td>
<td>0.172</td>
<td>-0.027</td>
<td>-0.814</td>
<td>0.309</td>
</tr>
<tr>
<td>Age (years)</td>
<td>0.733</td>
<td>-0.173</td>
<td>-0.025</td>
<td>0.196</td>
<td>0.533</td>
</tr>
<tr>
<td>Fasting Blood Glucose (mg/dL)</td>
<td>0.508</td>
<td>0.173</td>
<td>0.345</td>
<td>0.396</td>
<td>0.067</td>
</tr>
<tr>
<td>Post-prandial Blood Glucose (mg/dL)</td>
<td>0.042</td>
<td>-0.139</td>
<td>0.945</td>
<td>0.081</td>
<td>-0.125</td>
</tr>
<tr>
<td>Height (in)</td>
<td>0.190</td>
<td>0.856</td>
<td>0.111</td>
<td>-0.372</td>
<td>-0.162</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>-0.152</td>
<td>-0.079</td>
<td>-0.007</td>
<td>0.779</td>
<td>0.098</td>
</tr>
<tr>
<td>Systolic Blood Pressure (mmHg)</td>
<td>0.884</td>
<td>-0.063</td>
<td>-0.286</td>
<td>-0.055</td>
<td>-0.071</td>
</tr>
<tr>
<td>Diastolic Blood Pressure (mmHg)</td>
<td>0.654</td>
<td>-0.597</td>
<td>0.009</td>
<td>-0.076</td>
<td>-0.288</td>
</tr>
<tr>
<td>Heart Rate During Inhalation (beats/min)</td>
<td>0.328</td>
<td>-0.766</td>
<td>0.074</td>
<td>0.276</td>
<td>-0.372</td>
</tr>
<tr>
<td>Heart Rate During Exhalation (beats/min)</td>
<td>-0.080</td>
<td>-0.003</td>
<td>0.008</td>
<td>-0.108</td>
<td>0.928</td>
</tr>
<tr>
<td>Pepperoni Pizza Consumed (slices)</td>
<td>-0.145</td>
<td>0.361</td>
<td>( \textbf{0.820} )</td>
<td>-0.077</td>
<td>0.140</td>
</tr>
<tr>
<td>Cheese Pizza Consumed (slices)</td>
<td>( \textbf{0.813} )</td>
<td>0.221</td>
<td>0.118</td>
<td>-0.141</td>
<td>-0.157</td>
</tr>
<tr>
<td>Total Pizza Consumed (Calories)</td>
<td>0.118</td>
<td>0.934</td>
<td>0.124</td>
<td>0.092</td>
<td>-0.122</td>
</tr>
</tbody>
</table>
consisted of subjects with high fasting blood glucose, high post-prandial blood glucose, high systolic blood pressure, who were tall and had high BMIs. This group represents the subjects with metabolic syndrome and made up 22.25% of the participants.

Factor 2 consisted of subjects who had consumed a larger amount of pepperoni pizza and total pizza. Factor 3 consisted of subjects with high post-prandial blood glucose and high heart rate during exhalation. Factor 4 consisted of subjects with low papillae density who consumed a large amount of cheese pizza. Factor 5 consisted of subjects with high fasting blood glucose and high heart rate during inhalation. These remaining four factors were judged to be unrelated to metabolic syndrome.

Discussion

The results of this study demonstrate a significant relationship between many of the measurements including: a) BMI and fungiform papillae density, b) BMI and age, c) BMI and fasting blood glucose, d) BMI and systolic blood pressure, e) age and fasting blood glucose, f) age and systolic blood pressure, and g) age and diastolic blood pressure. These correlations indicate that children with a larger BMI have a higher fungiform papillae density, fasting blood glucose, and systolic blood pressure. Also, older children have a higher BMI, fasting blood glucose, systolic blood pressure, and diastolic blood pressure. These results suggest that BMI, fasting blood glucose, blood pressure and possibly height should all be included as risk factors in the definition of metabolic syndrome. Also, different cut points for the measurements included in the definition of metabolic syndrome will probably need to be identified for different age groups, given the significant correlation of many of these measures with age. Further research will need to be done to determine the values of these cut points.
The findings of this study, which indicate that BMI, fasting blood glucose, and blood pressure are important risk factors in metabolic syndrome, are corroborated by other published findings. In a study by Lambert et al. (2004), the authors’ objective was to estimate the prevalence of insulin resistance syndrome in a sample of adolescents in Quebec, Canada. The authors included BMI (kg/m²), triglycerides (mmol/l), insulin (mmol/l), systolic and diastolic blood pressure (mmHg) and LDL and HDL cholesterol (mmol/l) in their definition and used age and sex specific cut points. The results indicated that BMI, blood glucose, and blood pressure are components of metabolic syndrome.

In a study by Weiss et al. (2004), the authors investigated the effect of varying degrees of obesity on the prevalence of metabolic syndrome and the relation of metabolic syndrome with insulin resistance. The results demonstrated that the prevalence of the metabolic syndrome increases with increasing obesity, reaching 50% in severely obese children. The authors also demonstrate a significant correlation between the prevalence of metabolic syndrome and increasing insulin resistance. These results indicate that metabolic syndrome increases with the severity of obesity and severity of insulin resistance.

In a study by Golley et al. (2006), the authors’ objective was to assess the implications of variation in metabolic syndrome definition on metabolic syndrome prevalence estimates in a population of overweight and mildly obese children. The results showed that 0-4% of the subjects were classified as having metabolic syndrome under the adult definition. However, 39-60% of subjects were classified as having metabolic syndrome with varying child definitions. The four different child definitions consisted of varying cut points of glucose (mmol/l), triglycerides (mmol/l) HDL cholesterol (mmol/l), systolic blood pressure (mmHg), BMI (kg/m²), waist circumference (cm), and insulin (pmol/l). The results indicate that the prevalence of
metabolic syndrome depend greatly on the definition chosen, with the prevalence increasing when child definitions are used and insulin is included as a risk factor.

In a study by Cali et al. (2008), the authors investigated the metabolic abnormalities underlying the prediabetic status of isolated impaired fasting glucose (IFG), isolated impaired glucose tolerance (IGT), and combined IFG/IGT in obese youth. The results demonstrated that in obese youth, IFG is linked to alterations in glucose sensitivity of first-phase insulin secretion and liver sensitivity. The IGT group is affected by a more severe degree of peripheral insulin resistance and reduction in first-phase secretions. IFG/IGT is marked by a profound insulin resistance and by a new additional defect in second-phase insulin secretion.

Numerous studies, however, also point to the importance of other risk factors for childhood metabolic syndrome, such as triglycerides, cholesterol, and other blood measures. In another study by Lambert et al. (2004), the authors investigated the distribution of high-sensitivity C-reactive protein (CRP) and its association with components of metabolic syndrome. The results demonstrated a strong relationship between CRP concentrations and BMI and fasting insulin values. Increased CRP was also linked to high triglycerides and low HDL cholesterol concentrations, which suggests that increased CRP is correlated with a worsening of the lipid profile. These results indicate that the metabolic correlates of excess weight, including a state of low-grade systemic inflammation, are detectable early in life.

In a study done by Pinhas-Hamiel et al. (2007), the authors’ objective was to describe the lipid profile and insulin changes seen in obese children and adolescents at different stages of puberty. The main finding of the study was that, in the obese population of 5- to 17-year-olds, the combination of elevated triglycerides and very-low-density lipoprotein cholesterol and low
high density lipoprotein cholesterol levels place them at greater cardiovascular risk than their non-obese peers, even when adjusted for changing lipids and lipoproteins during puberty.

In a study done by Eisenmann et al. (2007), the authors investigated the relationships among fatness and aerobic fitness on indices of insulin resistance and sensitivity in children. The results showed that insulin sensitivity and secretion variables were significantly different between the normal-weight children and the overweight and obese subjects. Fasting insulin, homeostasis model assessment, quantitative insulin sensitivity check index, and insulinogenic index were significantly different between the overweight and obese subjects. Also, the high fitness group possessed a better insulin sensitivity profile. Generally, the normal-weight-high-fit group had the best insulin sensitivity profile, and the obese-unfit group had the worst. These results indicate that aerobic fitness attenuates the difference in insulin sensitivity within BMI categories, emphasizing the role of fitness even among over-weight and obese children.

Unfortunately, physical fitness, triglycerides, and cholesterol measurements were not obtained in my study. This was due to budget limitations, staff limitations, necessity of a doctor’s permission, and the invasive nature and pain of collection methods for young subjects. Regrettably, this information would have been extremely valuable to the study, and the lack of data on these potential risk factors is a notable limitation.

I also expected that the density of taste receptors and food selection might be associated with metabolic syndrome. A study by Bartoshuk (2006) demonstrated correlations between taste receptor density, BMI, and ingestion of sweet foods. Although in my study obesity was found to be significantly correlated with the density of taste receptors (with obese children having more receptors), food selection was not. It may be that there was not a big enough difference between cheese and pepperoni pizza. I expected that obese children would select the pepperoni pizza
with (50% more) higher calories. Perhaps if I had offered pizza and a low-calorie lunch like a salad, I might have observed a difference in food selection between overweight and normal-weight children.

In conclusion, the findings of this study indicate that BMI, fasting blood glucose, and blood pressure are important risk factors in metabolic syndrome. However, physical fitness, triglycerides, and cholesterol levels were not studied and need to be included in future studies. In addition, the role of density of taste receptors and food selection in metabolic syndrome need further investigation. It is imperative that investigators develop a universally accepted definition for metabolic syndrome in children, in order that medical professionals can identify and treat children with metabolic syndrome as early as possible.
Literature Cited


