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Abstract

The prevalence of overweight and obesity among children and adolescents has increased considerably over the last few decades. As a result, increasing numbers of American children are developing multiple risk factors for cardiovascular disease, type II diabetes, hyperinsulinemia, hypertension, dyslipidemia and hepatic steatosis.

This thesis examines the use of Monte Carlo computer simulation for understanding risk factors associated with childhood overweight. A computer model is presented for predicting cardiovascular risk factors among overweight children and adolescents based on BMI levels.

The computer model utilizes probabilities from the 1999 Bogalusa Heart Study authored by David S. Freedman, William H. Dietz, Sathanur R. Srinivasan and Gerald S. Berenson. The thesis examines strengths, weaknesses and opportunities associated with the developed model. Utilizing this approach, organizations can insert their own probabilities and customized algorithms for predicting future events.

Implications in using Monte Carlo Simulation in Predicting Cardiovascular Risk Factors among Overweight Children and Adolescents

A Stochastic Computer Model
based on probabilities from the Bogalusa Heart Study

July 17, 2007

By Stephen Heimbigner

Georgia State University
Institute of Public Health

A thesis submitted to the Faculty of the Graduate School of Georgia State University in partial fulfillment of the requirements for the Degree of Master of Public Health

Atlanta, Georgia

Approval

Implications in using Monte Carlo Simulation in Predicting Cardiovascular Risk Factors among Overweight Children and Adolescents

A Stochastic Computer Model based on probabilities from the Bogalusa Heart Study

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I. Introduction

The prevalence of overweight and obesity among children and adolescents has increased considerably over the last few decades. According the American Medical Association, the prevalence of overweight tripled in children and adolescents aged 6 – 19 years between 1980 and 2002 (Ogden, Carroll, Curtin, et al. 2006, p1549). As this trend continues, increasing numbers of American children are developing multiple risk factors for cardiovascular disease, type II diabetes, hyperinsulinemia, hypertension, dyslipidemia and hepatic steatosis. For the majority, health-related consequences begin in childhood and continue well into adulthood.

In response to this problem, organizations across America are banding together in the fight against childhood overweight. These partnerships focus on a variety of issues ranging from behavior to nutrition to physical activity. However, limited resources require organizations to carefully select only the most effective and efficient interventions. These decisions require thorough evaluation of national trends, scientific evidence and long-term strategies.

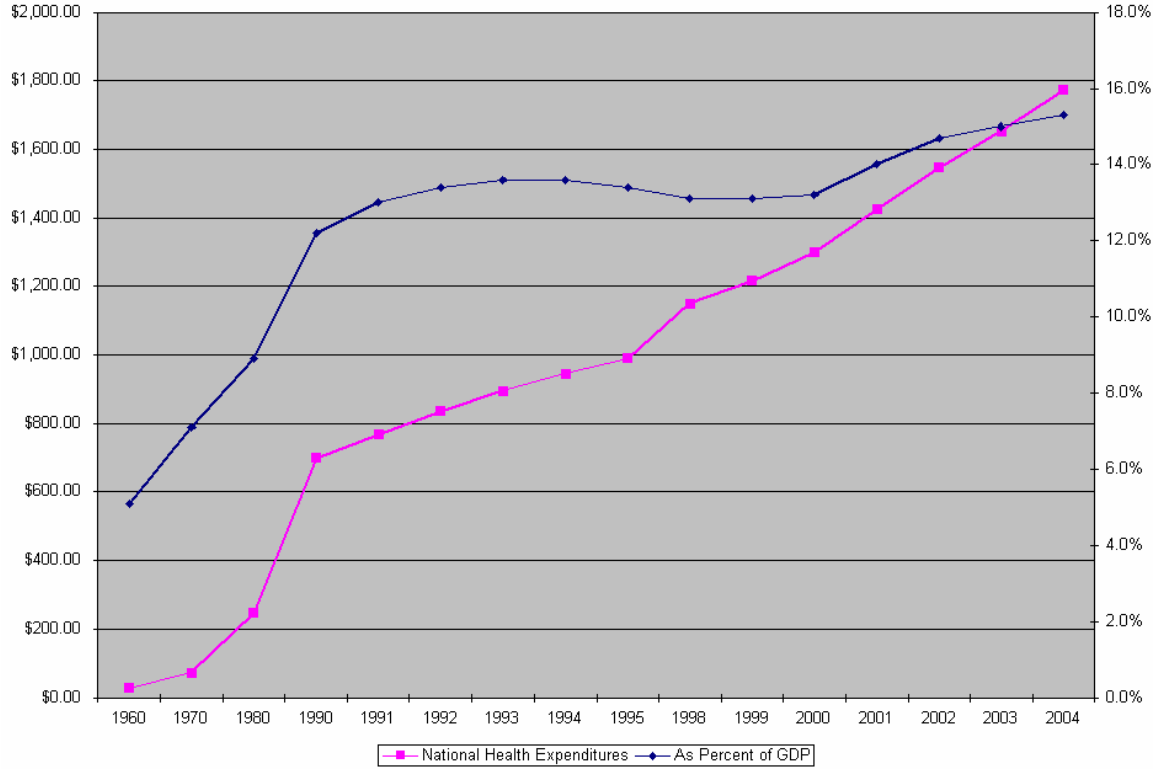
Organizations seeking to identify successful strategies require access to a wide variety of effective decision-making tools. The purpose of this thesis is to examine the use of Monte Carlo computer simulation as a tool for assisting organizations in identifying effective strategies for fighting childhood overweight. Utilizing this approach, organizations can insert their own probabilities and customized algorithms for predicting future events.

II. Background

The problem of overweight and obesity in the U.S. is not just a personal issue but rather a problem that impacts the quality of life, economic performance and

physical/mental status of whole populations. For example, consider the implications of overweight on the U.S. economy. Significant attention is given to the rising cost of health care. Health expenditures as a percentage of GDP in the United States have increased from less then three percent in the 1970's to approximately 16 percent in 2004 (see Figure II-1). The United States spends more on health care, in terms of per capita health spending, than any other nation members of the Organization for Economic Cooperation and Development (OECD). Considerations for many factors including quality, capacity and innovation are required before making judgments regarding the positive and/or negative implications of these spending trends. However, it is not disputed that health care expenditures are significant and growing.

Figure II-1 Total national health expenditures and as a percentage of GDP



Source: Custer, William S. (January, 2006). HA8250: Health Economics and Financing. Class Lecture 1 Georgia State University

Researchers project that health spending will increase to $3.4 trillion, or almost 20% of the GDP by 2013 (Hefler, Smith, Keehan, et al. 2004, p82). To undertake any serious attempt at controlling cost, policymakers must seek to more fully integrate public health into the U.S. health care system. It is usually cheaper to prevent illness, than to treat illness.

Chronic disease

In an effort to effectively control health care cost, the U.S. must focus on the problem of chronic disease. Chronic conditions are defined as illnesses or impairments that last a year or longer. According to the CDC's National Center for Chronic Disease Prevention and Health Promotion, more than 90 million Americans live with chronic illnesses and chronic diseases account for more than 75% of the nation's $1.4 trillion of medical care costs (National Center for Chronic Disease Prevention and Health Promotion, 2005, p3).

Chronic diseases, such as cardiovascular disease (primarily heart disease and stroke), cancer, and diabetes, are among the most prevalent, costly, and preventable of all health problems (National Center for Chronic Disease Prevention and Health Promotion, 2005, p2).

Overweight – A major contributor to chronic disease

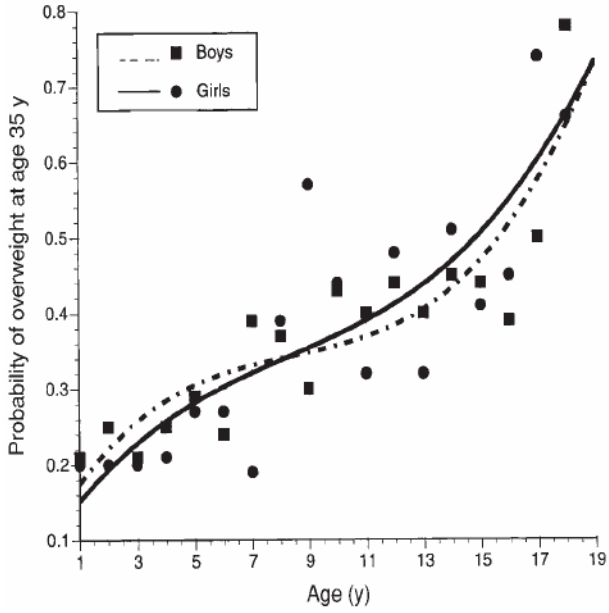
Research shows that "the risk of developing diabetes, gallstones, hypertension, heart disease and stroke increases with severity of overweight among both women and men" (Field, Coakley, Must, et al. 2001, p1581).

According to Calle and Walker-Thurmond, "In both men and women, body-mass index was significantly associated with higher rates of death due to cancer of the esophagus, colon and rectum, liver, gallbladder, pancreas, and kidney; the same was true

for death due to non-Hodgkin's lymphoma and multiple myeloma. Significant trends of increasing risk with higher body-mass-index values were observed for death from cancers of the stomach and prostate in men and for death from cancers of the breast, uterus, cervix, and ovary in women" (Calle, Rodriguez, Walker-Thurmond, et al. 2003, p1625).

As the number of overweight children and adolescents in the U.S. increases so will the number of overweight adults. Figure II-2 shows the probability of overweight at age 35 predicted from childhood BMI at the 95th percentile. According to Guo and Chumlea "Body mass index values at or above the 75 percentile are associated with increased morbidity and mortality in adulthood, and there are significant correlations between BMI values in childhood and in adulthood (Guo and Chumlea 1999, p145)

Figure II-2 Probability of overweight at age 35 predicted from childhood BMI at the 95th percentile



Source: Guo, S.S., Chumlea, W.C. (1999) Tracking of body mass index in children in relation to overweight in adulthood. The American Journal of Clinical Nutrition, 145, 145-147.

Health related consequences of child and adolescent overweight

The problem of overweight in children and adolescent is associated with several health-related consequences. The negative impact of these consequences may be

experienced in childhood and/or be experienced later on in adulthood. Overweight children and adolescents are at an increased risk for:

Cardiovascular Disease – Risk factors include abnormal cholesterol levels, hypertention, elevated triglycerides and glucose intolerance. Studies have shown "an evolving epidemic of cardiovascular risk in youth, as evidence by an increase in the prevalence of overweight' (Sorof, Lai, Turner, et al. 2004, p475).

Psychosocial Risks and Discrimination – Overweight children are often targets of early social discrimination. Social stigmatization and negative stereotyping can cause psychological stress and low self-esteem which, in turn, can hinder academic and social functioning that persists well into adulthood (CDC, 2007). Other social and emotional health consequences include social marginalization, teasing/bullying, depression and negative body image (Institute of Medicine, 2004, p2).

Glucose Intolerance – a pre-diabetic state, that is associated with insulin resistance and increased risk of cardiovascular pathology (Institute of Medicine, 2004, p2).

Diabetes Mellitus Type II / Insulin Resistance – What was once considered primarily an adult disease, type 2 diabetes has increased dramatically in children and adolescents. Overweight and obesity are closely associated with type 2 diabetes (Pi-Sunyer, 2002, p23S).

Hyperinsulinemia – A condition where excess levels of circulating insulin are in the blood. It is not diabetes, but it is often associated with metabolic syndrome and type 2 Diabetes (Pi-Sunyer, 2002, p22S).

Dyslipidemia – Overweight is associated with disruptions in the amount of lipids in the blood (Institute of Medicine, 2004, p2).

Hepatic Steatosis (a.k.a. fatty liver) –A reversible condition where large vacuoles of lipid accumulate in hepatocytes (the cells of the liver). Hepatic Steatosis is a health condition associated with increased weight (CDC, 2007, p1).

Other associated health conditions include orthopedic problems (Institute of Medicine, 2004), sleep apnea (CDC, 2007), gallstones (Institute of Medicine, 2004), asthma (Gennuso, Epstein, Paluch, et al. 1998), reproductive complications (Cnattingius, Bergstrom, Lipworth, et al. 1998) and menstrual abnormalities (Institute of Medicine, 2004).

Given the correlation between overweight children and overweight adults, health conditions associated with childhood overweight expand to include cancer and arthritis.

Fourteen percent of cancer deaths among men and 20% of cancer deaths among women may be due to overweight and obesity (Calle, Rodriguez, Walker-Thurmond, et al. 2003). Arthritis is the leading cause of disability in the United States. According to the U.S. Department of Health and Human Services (2007), the risk of developing arthritis increases by 9-13% for every two-pound increase in weight.

Interventions for overweight (and its corresponding chronic diseases) will require multifaceted approaches that seek to reverse years of cultural, behavioral and social norms. Interventions must address root cause, begin early in life to establish lifelong pattern of behavior and utilize effective methodologies for tracking progress.

Tracking overweight: National Health and Nutrition Examination Surveys (NHANES)

Two primary tools for tracking overweight in children and adolescents include the National Health and Nutrition Examination Survey (NHANES) and the Centers for Disease Control and Prevention growth charts.

In 1956, Congress passed the National Health Survey Act providing legislative authority for a recurring survey to provide statistical data on the amount, distribution, and effects of illness and disability in the United States. Three sources of data collection fulfilled this purpose.

- Direct interviews with survey participants
- Clinical tests, measurements and physical examinations
- Information retrieved from hospitals, clinics and doctors offices

In compliance with the National Health Survey Act, three initial surveys were performed.

1. 1960-62—National Health Examination Survey I (NHES I) – Focused on selected chronic disease of adults aged 18-79;
2. 1963-65—National Health Examination Survey II (NHES II) - Focused on the growth and development of children aged 6-11; and

3. 1966-70—National Health Examination Survey III (NHES III) - Focused on the growth and development of children aged 12-17

In 1970, the Secretary of the Department of Health directed that additional emphasis be placed on nutrition. As a result, the National Nutrition Surveillance System was implemented. The purpose of the system was to measure and track the nutritional status of the U.S. population.

Data from both systems were combined in the 1970's to form the National Health and Nutrition Examination Surveys (NHANES). Four surveys were conducted between 1970 and 1994.

- 1971-75—National Health and Nutrition Examination Survey I (NHANES I)
- 1976-80—National Health and Nutrition Examination Survey II (NHANES II)
- 1982-84—Hispanic Health and Nutrition Examination Survey (NHANES)
- 1988-94—National Health and Nutrition Examination Survey III (NHANES III)

Since 1999, the NHANES survey has been performed annually. Each year, approximately 7,000 randomly selected residents across the United States have the opportunity to participate (NCHS, 2007). Today, the survey is a valuable tool in providing objective assessment data of health status and overweight for individuals living in the United States.

Tracking overweight: Centers for Disease Control growth charts

In 1977, the National Center for Health Statistics (NCHS) developed a series of growth charts for the purpose of assessing the development of children and youth. The growth charts were developed utilizing data from the Fels Research Institute. Data consolidated empirical data of youth between the years 1929 and 1975. In 1978, the Centers of Disease Control and Prevention created a normalized version of the NCHS

percentiles to serve as an easy reference for pediatricians (Dibley, Goldsby, Staehling, et al. 1987, p736).

The 1977 NCHS growth charts gained national and international recognition as a standard for assessing the health status of infants and youth. The charts served as a cornerstone in research and are referenced in numerous studies evaluating prevalence, trends, population comparisons and interventions. At the international level, the World Health Organization (WHO) adopted the 1977 charts as standard reference (World Health Organization, 1978).

As the charts gained in popularity, they also underwent scrutiny. The primary issues centered on the validity of the Fels data. Inconsistencies include mismatches between NCHS percentiles and 1978 versions of normalized data, methodologies used for adjusting adolescent data versus younger children, over-representation of formula fed infants and non-representative datasets. At the time, these data were the best available and limitations were clearly stated in the initial release.

To address these issues the Centers for Disease Control and Prevention released a series of updated growth charts in May of 2000 (see Appendix A). Today, these same growth charts are the recommended standard for assessing children in the United States. The measurement data for creating the revised growth charts were obtained from a series of sources including:

- National Health Examination Survey (NHES), Cycles II and III
- National Health and Nutrition Examination Survey (NHANES) I, II, and III
- U.S. Vital Statistics
- Wisconsin Vital Statistics
- Missouri Vital Statistics
- Fels Longitudinal Study
- Pediatric Nutrition Surveillance System

Survey-specific sample weights were applied to the national survey sample data to assure representation of the U.S. population according to age, gender, and racial/ethnic composition at the time the surveys were conducted (CDC, 2007).

Defining overweight in children and adolescents

Several methodologies exist for measuring overweight in children and adolescents. Methodologies include body mass index, skin fold thickness measurements utilizing calipers, underwater weighing, bioelectrical impedance, dual-energy x-ray absorptiometry (DXA) and computerized tomography. However, tracking overweight at the national level requires adoption and agreement towards a national standard. In identifying this standard, issues of quality, ease of use (i.e., required training and equipment) and cost come into consideration. Based on these factors, the CDC recommends use of body mass index (BMI) for population studies (CDC, 2006).

Quetelet index

The quetelet index (or body mass index) was invented between 1830 and 1850 by social scientist Adolphe Quetelet. The index is a statistical measure of the weight of a person scaled according to height. As the measurement gained popularity during the 1980's, the term was more commonly referred to as "body mass index". Both terms are used interchangeably throughout this thesis to prevent confusion between referenced studies and data sources.

BMI is one of the best measurements for measuring overweight and obesity in populations. Only height and weight are required, making BMI screening easy and inexpensive. BMI is calculated the same way for both adults and children. According to the CDC (2006), calculations for BMI are as follows:

Equation 1 BMI in kilograms and meters

Kilograms and meters (or centimeters) = weight (kg) / [height (m)] 2

Equation 2 BMI in pounds and inches

Pounds and inches = weight (lb) / [height (in)] 2 x 703

Although BMI is the recommended standard for population studies, it is not without its limitations. According to the CDC (2006), BMI correlation to body fatness "varies by sex, race, and age". Examples of variance related to BMI include:

- At the same BMI, women tend to have more body fat than men do.
- At the same BMI, older people, on average, tend to have more body fat than younger adults do.
- Highly trained athletes may have a high BMI because of increased muscularity rather than increased body fatness.

Interpretations for BMI vary substantially between adult and children.

According to the CDC (2006), weight status for adults is classified as follows:

Table 1 Adult BMI weight status

BMI	Weight Status
Below 18.5	Underweight
18.5 – 24.9	Normal
25.0 – 29.9	Overweight
30.0 and Above	Obese

Source: Centers for Disease Control and Prevention (August 26, 2006). About BMI for Children and Teens. Retrieved March 10, 2007 from http://www.cdc.gov/nccdphp/dnpa/bmi/childrens_BMI/about_childrens_BMI.htm

The criteria for establishing weight status in children is slightly more complex. This is due to significant differences in amount of body fat between boys and girls as well as for specific age groups. According to the CDC (2006), child and adolescent weight status is classified as follows:

Table 2 Child and adolescent weight status

Weight Status Category	Percentile Range
Underweight	Less than the 5th percentile
Normal	5th percentile to less than the 85th percentile
Overweight	85th to less than the 95th percentile
Obese	Equal to or greater than the 95th percentile

Source: Centers for Disease Control and Prevention (August 26, 2006). About BMI for Children and Teens. Retrieved March 10, 2007 from http://www.cdc.gov/nccdphp/dnpa/bmi/childrens_BMI/about_childrens_BMI.htm

Percentile range is defined using the May 2000 growth charts (see Appendix A) based on a combination of data sources.

Trends in tracking overweight among U.S. children and adolescents

Utilizing the percentile ranges defined in Table 2, the prevalence of overweight and obesity among U.S. children and adolescents has increased considerably over the last few decades.

The Institute of Medicine (2004) found that:

> "Over the past three decades, the childhood obesity rate 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. At present, approximately nine million children over 6 years of age are considered obese." (IOM, 2004, p1)

For detailed prevalence data for children and adolescents who are "at risk of overweight" and/or "overweight" by sex, age, and racial/ethnic group (see Appendix B & C).

III. Literature review

The tools of modeling, analysis and simulation are widely used to assess systems that evolve dynamically and/or have behaviors that are uncertain. Nelson (1995) found

computerized simulation modeling to be a valuable asset in the following industries and applications.

Manufacturing – capacity planning, inventory control and evaluation of process quality

Health-care – hospital staffing and medical decision making

Computer applications – designing hardware configurations and operating-system protocols

Communication - evaluating network reliability

Economic – portfolio management and forecasting

Business – consumer behavior, product distribution and logistics

Biological – population genetics and epidemiology

The purpose of this thesis is to achieve the following:

Research Objective: This thesis examines the use of Monte Carlo computer simulation for understanding cardiovascular risk factors associated with childhood overweight. A computer model is presented for predicting cardiovascular risk factors among overweight children and adolescents based on BMI percentiles.

The primary benefits of computer modeling include:

Explaining relationships / sensitivity - For example, how do increases in childhood overweight affect increases in risk factors for elevated triglycerides?

Predicting future events – As an example, if current trends in childhood BMI continue, what is the expected number of children at risk due to high blood pressure in five years?

Examining "what if" scenarios - In other words, if one variable is modified – what changes are expected in other variables within the system? For example, if the rate in number of children who are "overweight" is reduced by half – What is the expected number of children with elevated total cholesterol?

Monte Carlo modeling

A Monte Carlo simulation is a statistical method involving computer simulation in which data is generated randomly, enabling assessment of the probabilities of certain known outcomes. For this study, a random number generator is used to replicate both

weight status and the occurrence of specific cardiovascular risk factors in children and adolescents.

Monte Carlo simulation is utilized in several studies for predicting future events and outcomes in the field of public health. For example, Bray (2002) utilized Markov Chain Monte Carlo (MCMC) simulation to address a 5-year delay in the publishing of cancer incidence and mortality rates. Bray noted that current health models are rarely utilized because of oversimplistic methodologies and/or models that are dependent on questionable parametric assumptions. Bray proposes a new model based on MCMC simulation and utilization of Bayesian statistics.

Stuart and colleagues (2003) utilized Monte Carlo experiments to simulate data loss in testing the robustness of proportion-based quality indicators for asthma. Through the use of Monte Carlo modeling, asthma quality indicators measures were determined highly robust to systematic and random data loss.

Chen, Yen and Tung (2001) modeled the disease natural history of Type 2 diabetes mellitus using Monte Carlo Markov processes. The goal of the study was to determine the cost effectiveness of mass screening in Taiwan. Two separate screening regimes were compared with a control group. Direct costs and utilities were incorporated to calculate the incremental costs per life-years gained and per quality-adjusted life-years for biennial and five-yearly screening regimes. Through the use of Monte Carlo modeling, the study showed 5-year interval mass-screening for Type 2 diabetes mellitus to be cost-effective in Taiwan.

Overview of the Bogalusa Heart Study

The computer model utilizes probabilities from the 1999 Bogalusa Heart Study published by Freedman, Dietz, Srinivasan and Berenson (The relation of overweight to

cardiovascular risk factors among children and adolescents: The Bogalusa Heart Study. *Pediatrics*, 103, 1175–1182). The objective of the Bogalusa Heart Study was to utilize quetelet index cut points to examine the relation of overweight to adverse risk factors levels. Table 3 shows the relationships between Quetelet index and adverse cardiovascular risk factors by age group.

Table 3 Relation of quetelet index to adverse risk factors, by age group

Quetelet Index Percentiles							
Ages 5-10 years	**<25**	**25-49**	**50-74**	**75-84**	**85-94**	**95-97**	**>97**
Sample Size	904	817	798	340	384	100	256
Total Cholesterol > 200 mg/dL	9	10	10	13	18	17	23
Triglycerides > 130 mg/dL	2	3	3	6	10	10	21
Low-Density Lipoprotein Cholesterol > 130 mg/dL	8	8	9	10	18	12	23
High-Density Lipoprotein Cholesterol < 35 mg/dL	5	5	6	4	8	7	18
Fasting Insulin > 95th Percentile	2%	2%	3%	3%	4%	10%	27%
Systolic Blood Pressure > 95th Percentile	2%	2%	4%	6%	7%	12%	22%
Diastolic Blood Pressure > 95th Percentile	2%	2%	4%	9%	7%	9%	14%
Ages 5-10 years	**<25**	**25-49**	**50-74**	**75-84**	**85-94**	**95-97**	**>97**
Sample Size	1189	1122	1249	611	763	210	424
Total Cholesterol > 200 mg/dL	6	6	7	9	15	12	19
Triglycerides > 130 mg/dL	3	4	5	7	12	18	32
Low-Density Lipoprotein Cholesterol > 130 mg/dL	4	4	6	9	13	12	21
High-Density Lipoprotein Cholesterol < 35 mg/dL	6	9	10	12	14	16	21
Fasting Insulin > 95th Percentile	1%	1%	3%	2%	5%	10%	25%
Systolic Blood Pressure > 95th Percentile	2%	4%	6%	4%	7%	5%	11%
Diastolic Blood Pressure > 95th Percentile	4%	5%	5%	5%	4%	4%	9%

Source: Freedman. D.S., Dietz W.H., Srinivasan. S.R., Berenson. G.S., (1999) The relation of overweight to cardiovascular risk factors among children and adolescents: The Bogalusa Heart Study. Pediatrics, 103, 1175–1182.

The Bogalusa (Louisiana) Heart Study included seven cross-sectional examinations, each with a participation rate of >80% between 1973 and 1994. The study population was 43,000 (1/3 black, 2/3 white) schoolchildren between the ages of 5 and 17 years. Analysis was restricted to individuals who properly fasted and who had recorded values for weight, height, total cholesterol and systolic blood pressure. The resulting

sample included 9,167 schoolchildren between the ages of 5 and 17 years (Freedman, Dietz, Srinivasan, et al. 1999, p1175).

The Bogalusa study provides valuable insight into cardiovascular risk factors among children and adolescents. Additionally, the study provides the opportunity for building a simulation that otherwise would not be possible. However, the study itself provides only static information - a snapshot in time. It provides great insight into the prevalence and even incidence of cardiovascular risk factors among children and adolescents but does not provide any prediction in how risk factors change in relation to time and/or weight status.

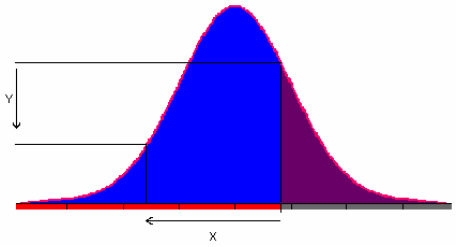
Simulation, on the other hand, is dynamic. Each iteration of a simulation yields different results. Much like real life, conditions change from day to day. For example, suppose one's weight is measured once per week. In the first week, one weighed 175.12 lbs. In the second week, the probability that one would again weigh 175.12 lbs is highly improbable. One's weight today is much more likely to fall somewhere above or below 175.12 lbs.

Weight fluctuation may be due to a variety of variables. Some are attributed to what is called "natural variance": e.g., at the time of weight measurement an individual had not eaten breakfast, had lost water from a morning jog, etc. Some changes in weight are considered "significant": e.g., eating or exercised habits had changed, the individual had caught a virus, or became pregnant. Simulation seeks to explain both natural and significant variance through probability theory.

Additionally, simulation becomes helpful when stringing together multiple probability distributions. When the number of variables is small, then the calculations are easily performed. For example, consider the normal probability distribution in Figure

III-1. The y-axis represents the probability that a randomly selected individual's average daily duration of moderate exercise equals the corresponding duration in minutes (x-axis). The ability to compare probabilities for increased vs. decreased exercise is relatively easy.

Figure III-1 Example probability distribution



Now consider a slightly more complex model in Figure III-2. Assume, again that distribution A is a probability distribution for average level of exercise. If the individual's daily exercise level is significant enough to fall within the dark purple region, then the probability of getting a particular disease outcome is determined by distribution B. Otherwise, the probability of getting the particular disease is determined by distribution C. The final "Predicted Prevalence" is calculated using a combination of outputs from distributions B and C.

Figure III-2 Example of a chain of probability distributions

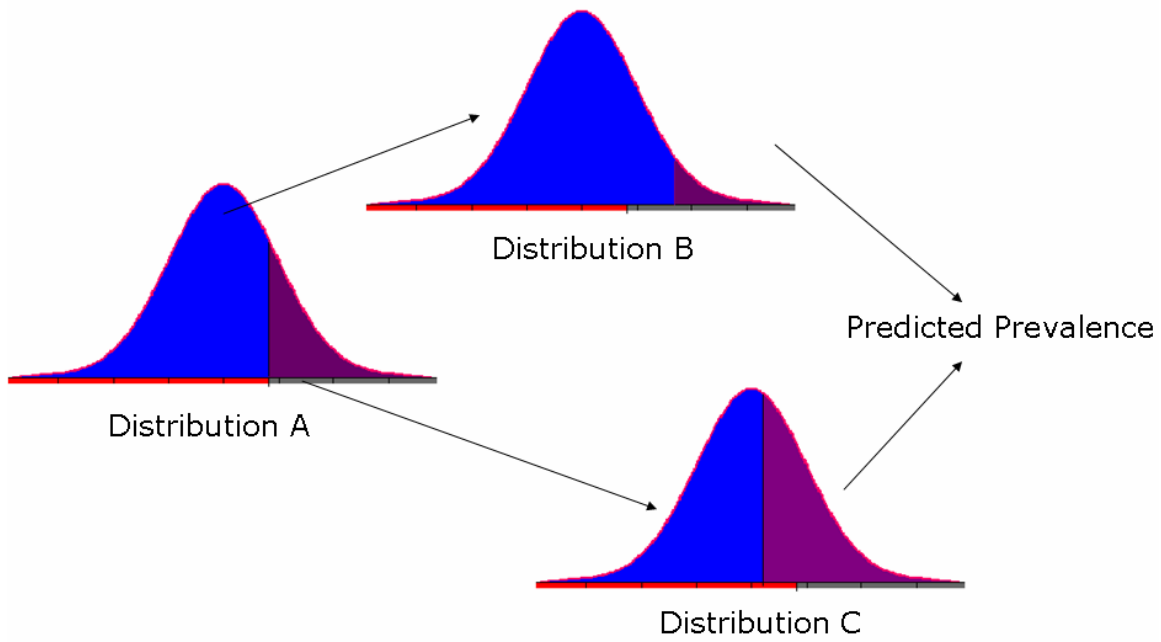


Figure 3-2 provides a good example of the complexity that derives from syndemics. "Syndemics" is a term invented to describe a set of linked health problems and is defined as two or more afflictions, interacting synergistically, contributing to excess burden of a disease in a population (CDC, January 2005). For a more in-depth explanation on modeling, see Computer Simulation Theoretical Example in Appendix D.

Through simulation, researchers can tweak probabilities to better understand the impact of certain system events. Simulation may help to answer questions such as:

How do reductions in BMI impact cholesterol levels?
What if interventions target the reduction of BMI for a particular sex and/or ethnicity group?
What if current trends in BMI continue for 5 years?
What if the trends in BMI stay the same but the risk of hypertension increases?

Simulation has proven helpful in addressing these and many more question of this type.

Simulation and Probability Theory

Two important laws are critical to the performance of a Monte Carlo simulation. They are the Law of Large Numbers and Bayes' Law. The Law of Large Numbers is a fundamental concept in probability. According to the law:

> *If an event of probability p is observed repeatedly during independent repetitions, the ratio of the observed frequency of that event to the total number of repetitions converges towards p as the number of repetitions becomes arbitrarily large.*

In other words, as an experiment is repeated over and over, the observed probability approaches the actual probability distribution.

The second law critical to simulation is Bayes Law. Before delving into this law, it is important to understand the two primary schools of thought for assigning probabilities to various applications: Frequentist and Bayesian interpretations.

Frequentists assign probabilities to random events based on subsets of a population as proportions of the whole (Durrett, 1994). For example, in the Bogalusa Heart Study 432 children ages 5 to 10 years of age are at risk for total cholesterol levels greater than 200 milligrams/deciliter (md/dL). The total sample size of children ages 5 to 10 screened for total cholesterol is 5,568. Based on these findings the proportion of children ages 5 to 10 with total cholesterol levels greater than 200 md/dL is 12%. In other words, using a frequentest view, the probability of a child ages 5 to 10 having a total cholesterol level greater than 200 md/dL is 0.12.

Bayesian interpretations (or Bayes' Law) is valid for both interpretations of probability. Bayes' Law relates a condition on the probability distribution (Durrett, 1994). In other words, probabilities are updated in light of new evidence. Using the example above, a randomly selected 5 to 10 year old has a 0.12 probability of having a

total cholesterol level exceeding 200 md/dL. If the 5 to 10 year old child, selected at random, is known to be overweight (i.e., the child has a quetelet index greater than 95%). This additional information may be used to update the original probability. In light of the additional information regarding the child's weight status, the child now has 0.17 probability of having a total cholesterol level exceeding 200 md/dL.

The simulation model in this study utilizes quetelet index as a conditional attribute for each randomly generated event. Probabilities for predicting adverse cardiovascular risk factors are calculated utilizing the principles of Bayes Law.

IV. Model Development

Utilizing a similar methodology as was described earlier, the cardiovascular risk factor model simulates trails based on single individuals. Each individual is first assigned a weight status using a quetelet index. Second, the individual is assessed against a series of probabilities (thresholds) to determine their susceptibility to various cardiovascular risk factors. Each probability is determined given the individuals assigned weight status (i.e., quetelet index).

The term “event” in probability refers to an unknown future result, while the term “system event” refers to a change in the status of a system (Nelson, 1995, p25). A system event is synonymous with implementation of an intervention. For example, a single event may represent a 5 to 10 year old who is assigned a quetelet index in the 88th percentile. By definition, this individual is considered “at risk of overweight”. The same child is then assessed for total cholesterol. If this child’s total cholesterol level is greater than 200 mg/dL, they are considered at risk for cardiovascular disease based on total cholesterol. A 5-10 year old child with a quetelet index equal to the 85th percentile has a probability of 0.157 for exceeding the 200 mg/dL threshold. Generating a random

number between zero and one using a uniform distribution provides the random number 0.235. Because 0.235 is greater than 0.157, this individual in not considered "at risk" for total cholesterol even though the child is "at risk of overweight". The same is repeated for multiple risk factors and for multiple trials until the Law of Large Numbers is achieved.

Two separate models are assessed. The first will model cardiovascular risk factors among children ages 5 to 10 years. The second will model cardiovascular risk factors among adolescents ages 11 to 17 years. These age groups are consistent with the age groups established in the Bogalusa Heart Study. Age group categories allow for more accurate predictions of individual quetelet index, risk factor susceptibility as well as changes in height and weight metrics due to puberty.

@RISK Version 4.5.3

The simulation utilizes @RISK version 4.5.3 (student version) released February of 2003. The tool is a proprietary product owned by the Palisade Decision Tools Corporation. @RISK 4.5 is a Monte Carlo simulation add-in for Microsoft Excel version 97 (8.0) or higher.

Model assumptions

As stated in the introduction, the purpose of this thesis is to examine the use of Monte Carlo computer simulation for understanding risk factors associated with childhood overweight. As such, it is hoped that future research will build and ultimately improve upon the presented concepts. Even the most robust and extensively developed models contain uncertainties and error. All simulation models have the potential for improvement. That said, simulation is built on probability theory and mathematics. Computer modeling is a statistically viable tool for modeling real-life situations and for

studying how stochastic systems work. "Stochastic" is a term meaning to have a random variable. A stochastic model is a tool for estimating potential outcomes by allowing for random variation. The more accurate the model, the better the model is in predicting outcomes.

In accordance with the scope and purpose of this thesis, the following assumptions apply:

- The model is subject to limitations in population sample sizes, sampling error and aggregation of data for ages 5-10 years and 11-17 years.
- The model collapses probabilities from Freedman et. al. into specific risk factor categories and does not account for the complexities of relationships that exist between risk factors. The purpose of this model is to illustrate the benefits in simulating cardiovascular risk factors among overweight children and adolescents and does not seek to explain all relationships that may exist between data points.
- The model is limited by the generalizations of calculating trend lines and in using quetelet index ranges for each predicted cardiovascular risk factor.
- The Monte Carlo simulation is performed for five iterations of 1,000 trials. Therefore, each simulation is limited to a total of 5,000 trials. This number of trials is assumed sufficient in achieving the Law of Large Numbers. Additionally, each iteration utilizes a different algorithm for generating numbers and therefore achieves greater randomness.

Model inputs

Thompson, Burmaster and Crouch are pioneers in the work of utilizing Monte Carlo techniques for quantifying uncertainty in public health risk assessments. According to their work:

> "The first step in the Monte Carlo simulation is to determine (continuous or discrete) probability distribution functions (PDFs) to describe each of the variable in the uncertainty analysis. In the simulation, each of many input variables can become a random variable with known or estimated PDF [or equivalently, a cumulative distribution function (CDF)]. Within this framework, a variable takes on a range of values with a known probability. Some distributions, for instance, are based on normal human variability and they come into play in the uncertainty analysis because we are uncertain who the person is that will actually be following the scenario"(Thompson, Burmaster, Crouch, 1992, p54).

In this model, two separate PDFs are developed and applied for obtaining quetelet index values (i.e., children ages 5-10 years of age and adolescents 11-17 years of age). The

quetelet index PDF utilizes a histogram of probabilities from the Bogalusa Heart Study (Table 4).

Table 4 BMI Probability Distribution (ages 5-10)

BMI Range	Frequency of Occurrence	Range	Probability for Range	Probability per Percentile
0 =< x < 25	904	25	0.2512	0.0100
25 =< x < 50	817	25	0.2270	0.0091
50 =< x < 75	798	25	0.2217	0.0089
75 =< x < 85	340	10	0.0945	0.0094
85 =< x < 95	384	10	0.1067	0.0107
95 =< x < 97	100	2	0.0278	0.0139
97 =< x < 100	256	3	0.0711	0.0237

Similar a histogram is created for adolescents ages 11-17 using probabilities established from the Bogalusa Heart Study.

Table 5 BMI Probability Distribution (ages 11-17)

BMI Range	Frequency of Occurrence	Range	Probability for Range	Probability per Percentile
0 =< x < 25	1189	25	0.2135	0.0085
25 =< x < 50	1122	25	0.2015	0.0081
50 =< x < 75	1249	25	0.2243	0.0090
75 =< x < 85	611	10	0.1097	0.0110
85 =< x < 95	763	10	0.1370	0.0137
95 =< x < 97	210	2	0.0377	0.0189
97 =< x < 100	424	3	0.0761	0.0254

Cardiovascular risk factors of childhood and adolescent overweight

The cardiovascular risk factor model, will direct each trial or randomly generated individual through a second series of equations. The equations determine the individual's probability for being "at risk" of cardiovascular disease based on a particular risk factor.

Using regression analysis, polynomial equations are derived to explain the relationship between quetelet index and the probability of being at risk for cardiovascular

disease due to a particular risk factor. Cardiovascular risk factors in scope for this analysis include:

- Total Cholesterol > 200 mg/dL
- Triglycerides > 130 mg/dL
- Low-Density Lipoprotein Cholesterol > 130 mg/dL
- High-Density Lipoprotein Cholesterol < 35 mg/dL
- Fasting Insulin > 95th Percentile
- Systolic Blood Pressure > 95th Percentile
- Diastolic Blood Pressure > 95th Percentile

Utilizing probabilities from Freedman et al. polynomial equations are developed to represent the relationships between BMI and cardiovascular risk factor probabilities. Figures IV-1 and IV-2 show the relationship of quetelet index (or BMI) in children and adolescents to the probability of total cholesterol exceeding 200 mg/dL.

Figure IV-1 Relationship of quetelet index in children ages 5-10 to probability of total cholesterol > 200 mg/dL

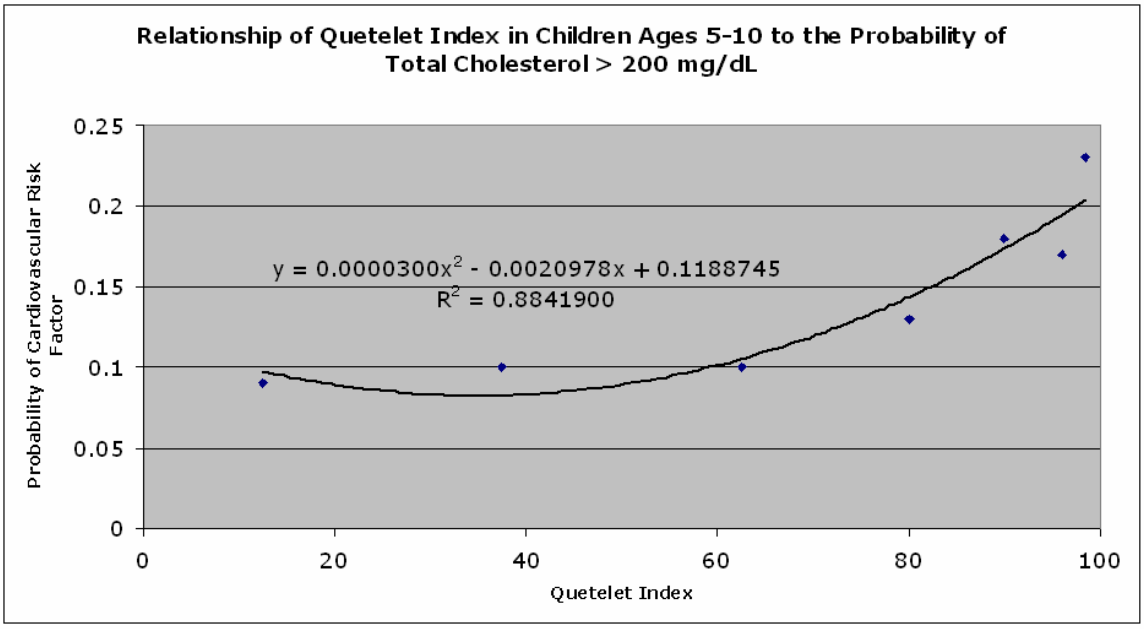
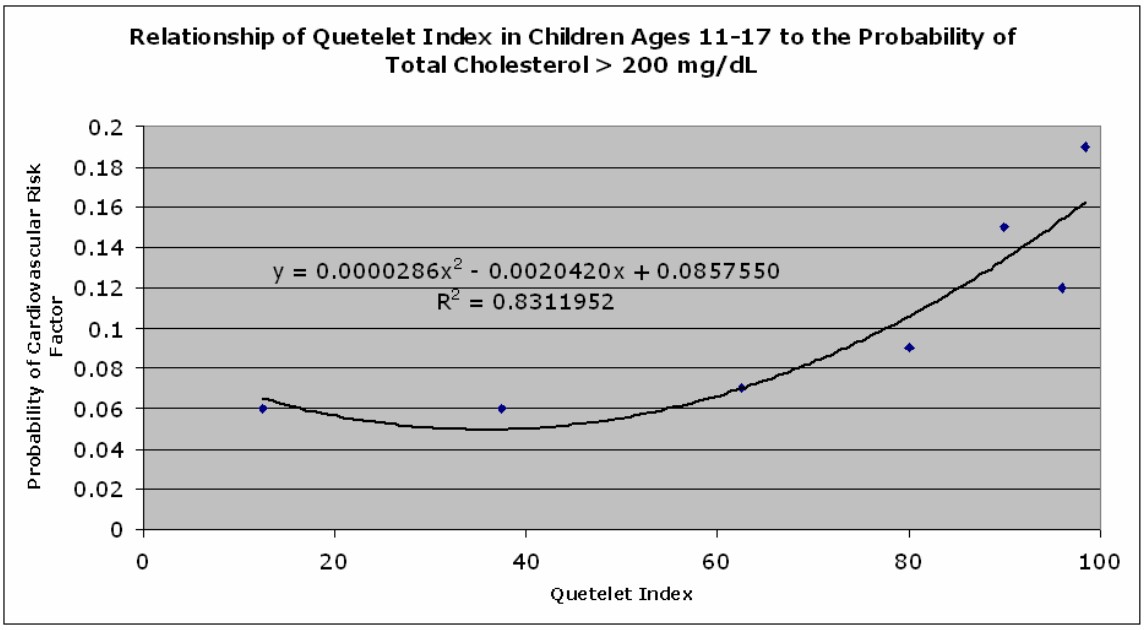


Figure IV-2 Relationship of quetelet index in children ages 11-17 to probability of total cholesterol > 200 mg/dL



Likewise, Equations 3 through 16 show the relationships for each cardiovascular risk factor by age group. . Graphs for each equation are also available in Appendix E.

Equation 3 - Probability of at risk for total cholesterol as a function of quetelet index (ages 5-10)

$$y = 0.0000300x2 - 0.0020978x + 0.1188745$$

x = probability of total cholesterol > 200 mg/dL; y = quetelet index

Equation 4 - Probability of at risk for total cholesterol as a function of quetelet index (ages 11-17)

$$y = 0.0000286x2 - 0.0020420x + 0.0857550$$

x = probability of total cholesterol > 200 mg/dL; y = quetelet index

Equation 5 - Probability of at risk for triglycerides as a function of quetelet index (ages 5-10)

$$y = 0.0000401x2 - 0.0030472x + 0.0633072$$

x = probability of Triglycerides > 130 mg/dL; y = quetelet index

Equation 6 - Probability of at risk for triglycerides as a function of quetelet index (ages 11-17)

$$y = 0.0000677x2 - 0.0053929x + 0.1072561$$

x = probability of Triglycerides > 130 mg/dL; y = quetelet index

Equation 7 - Probability of at risk for Low-Density Lipoprotein Cholesterol as a function of quetelet index (ages 5-10)

$$y = 0.0000315x2 - 0.0023502x + 0.1106534$$

x = probability of Low-Density Lipoprotein Cholesterol > 130 mg/dL; y = quetelet index

Equation 8 - Probability of at risk for Low-Density Lipoprotein Cholesterol as a function of quetelet index (ages 11-17)

$$y = 0.0000335x2 - 0.0022955x + 0.0687305$$

x = probability of Low-Density Lipoprotein Cholesterol > 130 mg/dL; y = quetelet index

Equation 9 - Probability of at risk for High-Density Lipoprotein Cholesterol as a function of quetelet index (ages 5-10)

$$y = 0.0000283x2 - 0.0024594x + 0.0859913$$

x = probability of High-Density Lipoprotein Cholesterol < 35 mg/dL; y = quetelet index

Equation 10 - Probability of at risk for High-Density Lipoprotein Cholesterol as a function of quetelet index (ages 11-17)

$$y = 0.0000187x2 - 0.0007838x + 0.0752449$$

x = probability of High-Density Lipoprotein Cholesterol < 35 mg/dL; y = quetelet index

Equation 11 - Probability of at risk for Fasting Insulin as a function of quetelet index (ages 5-10)

$$y = 0.0000582x2 - 0.0050417x + 0.0931682$$

x = probability of Fasting Insulin > 95th Percentile; y = quetelet index

Equation 12 - Probability of at risk for Fasting Insulin as a function of quetelet index (ages 11-17)

$$y = 0.0000548x2 - 0.0045987x + 0.0760686$$

x = probability of Fasting Insulin > 95th Percentile; y = quetelet index

Equation 13 - Probability of at risk for Systolic Blood Pressure as a function of quetelet index (ages 5-10)

$$y = 0.0000435x2 - 0.0033672x + 0.0661171$$

x = probability of Systolic Blood Pressure > 95th Percentile; y = quetelet index

Equation 14 - Probability of at risk for Systolic Blood Pressure as a function of quetelet index (ages 11-17)

$$y = 0.0000042x2 + 0.0001590x + 0.0217240$$

x = probability of Systolic Blood Pressure > 95th Percentile; y = quetelet index

Equation 15 - Probability of at risk for Diastolic Blood Pressure as a function of quetelet index (ages 5-10)

$$y = 0.0000183x2 - 0.0009286x + 0.0290296$$

x = probability of Diastolic Blood Pressure > 95th Percentile; y = quetelet index

Equation 16 - Probability of at risk for Diastolic Blood Pressure as a function of quetelet index (ages 11-17)

$$y = 0.0000037x2 - 0.0002198x + 0.0460476$$

x = probability of Diastolic Blood Pressure > 95th Percentile; y = quetelet index

High levels of insulin, systolic blood pressure and diastolic blood pressure were defined as those with greater than the 95th percentile for race, sex and age specific national standards.

Model outputs

Now that the model inputs are defined, Figures IV-3 and IV-4 provides an overview for the model architecture.

Figure IV-3 Cardiovascular Risk Factor Model (age 5-10)

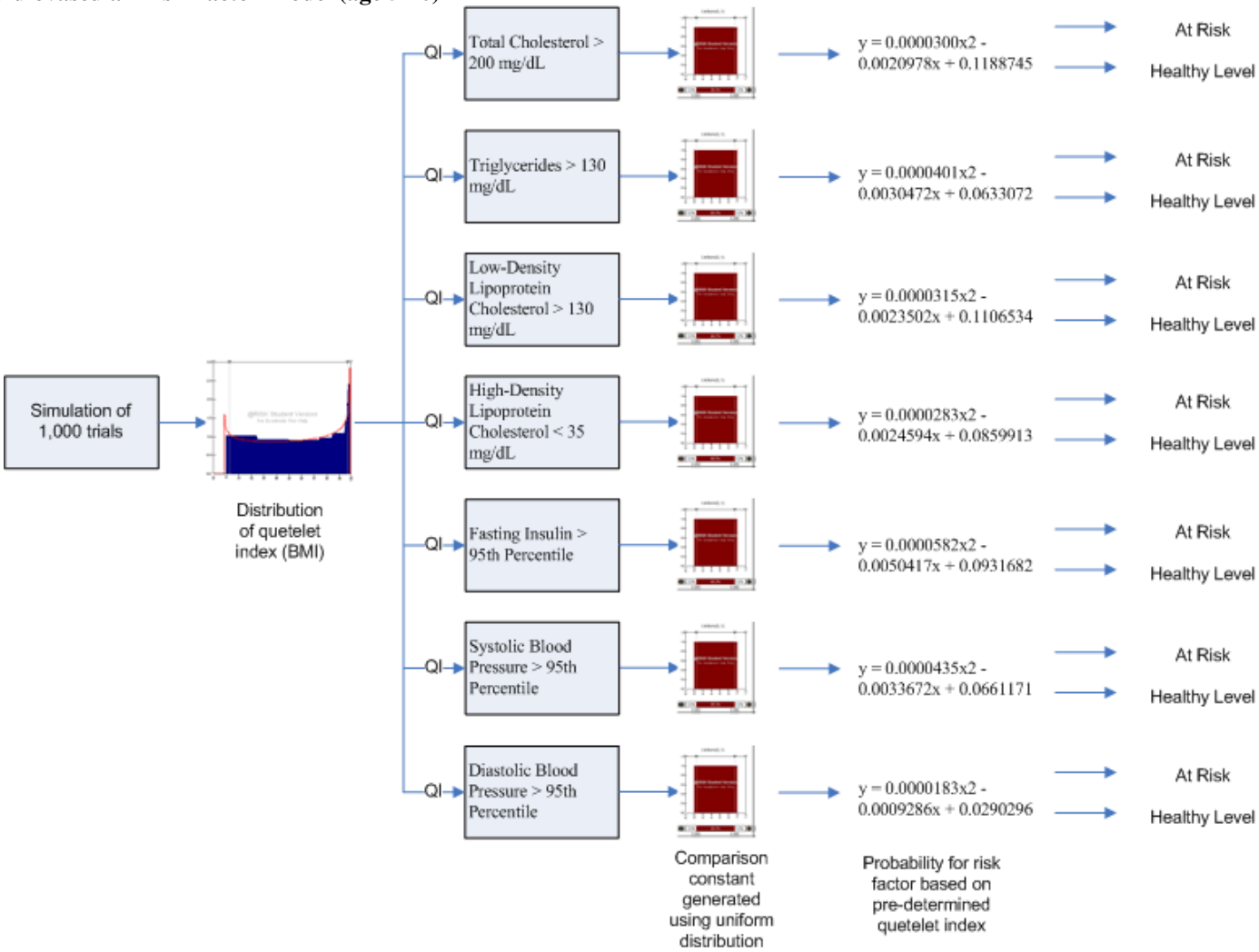
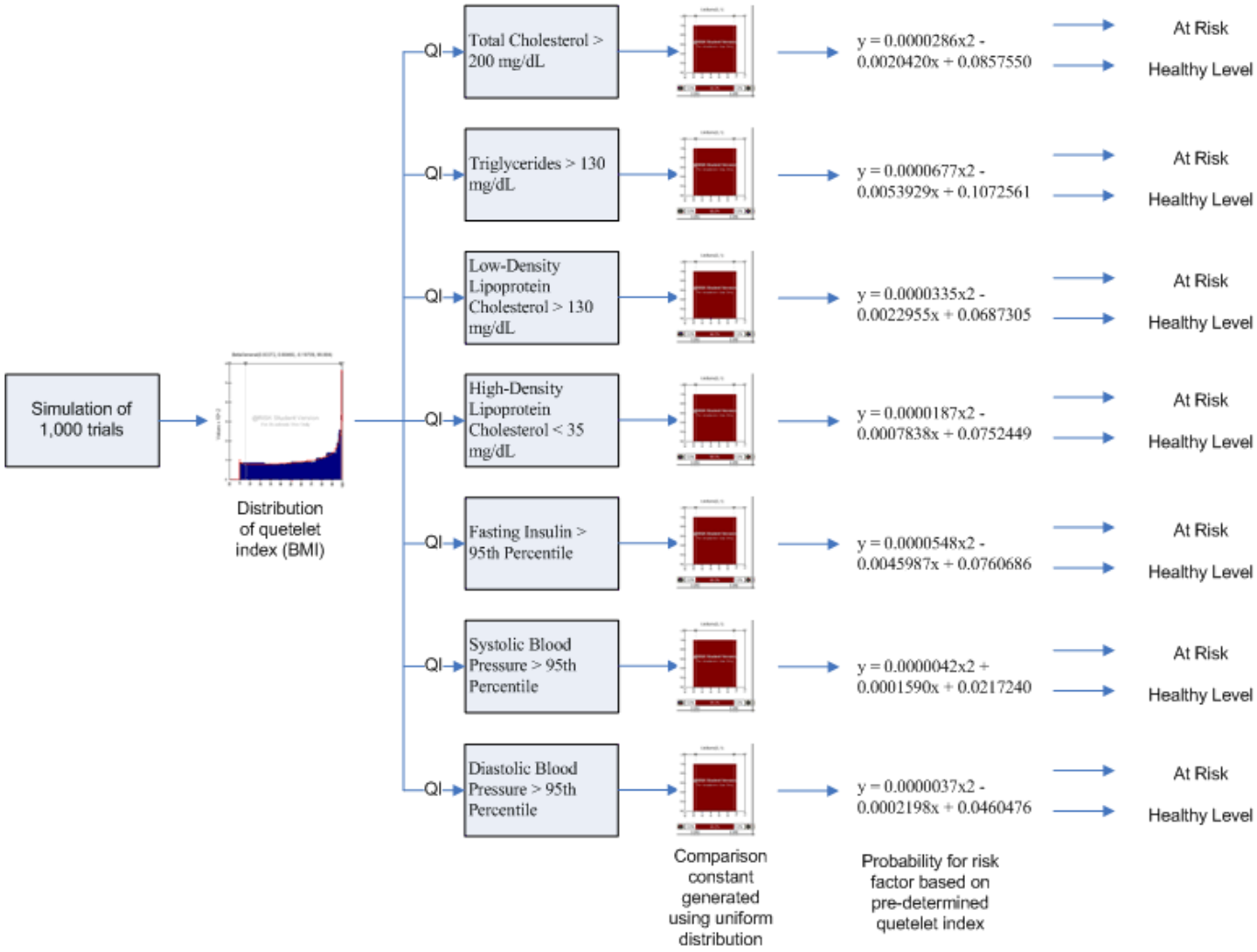


Figure IV-4 Cardiovascular Risk Factor Model (age 11-17)



Once the risk factor probabilities are established for an individual based on quetelet index, a uniform distribution is utilized as a comparison constant. In other words, say the probability for an individual being "at risk" due to total cholesterol is 0.25. A uniform distribution from 0.00 to 1.00 will randomly select a comparison constant. If the comparison constant is .36, then the individual in not "at risk" for total cholesterol (i.e., .36 > .25). If, however, the comparison constant were .19 the individual would be at risk for total cholesterol (i.e., .19 < .25).

Two additional outputs of the model include:

- Proportion of children and adolescents who are "At Risk for Overweight" but not "Overweight". Children and adolescents with a quetelet index greater than 85% but less than 95% (see Appendix A) are defined as "At Risk for Overweight" but not "Overweight".

- Proportion of children and adolescents who are "Overweight". Children and adolescents with a quetelet index greater than 95% (see Appendix A) are defined as "Overweight".

V. Discussion

Simulation results for adolescents 5 to 10 years of age.

The results from the first simulation model (Figure IV-3) for children ages 5 to 10 are provided in Tables 6 through 9. Total number of occurrences and percentages are shown for all trials (Table 6), children with BMI < 85th percentile (Table 7), children with BMI between the 85th and 95th percentiles (Table 8), and children with BMI > 95th percentile (Table 9).

Table 6 Simulation results for all children ages 5 to 10 years

Simulation results for all children ages 5 to 10 years				
	Yes	**No**	**Total**	**Percent**
Children "at risk for overweight" but who are not "overweight"	624	4376	5000	12.48%
Children who are "overweight"	383	4617	5000	7.66%
Total Cholesterol > 200 mg/dL?	645	4355	5000	12.90%
Triglycerides > 130 mg/dL?	276	4724	5000	5.52%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	540	4460	5000	10.80%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	322	4678	5000	6.44%
Fasting Insulin > 95th Percentile?	244	4756	5000	4.88%
Systolic Blood Pressure > 95th Percentile?	259	4741	5000	5.18%
Diastolic Blood Pressure > 95th Percentile?	212	4788	5000	4.24%

Table 7 Simulation results for healthy weight (quetelet index < 85th) children ages 5 to 10 years

Simulation results for healthy weight (quetelet index < 85th) children ages 5 to 10 years				
	Yes	**No**	**Total**	**Percent**
Total Cholesterol > 200 mg/dL?	455	3538	3993	11.39%
Triglycerides > 130 mg/dL?	155	3838	3993	3.88%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	367	3626	3993	9.19%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	221	3772	3993	5.53%
Fasting Insulin > 95th Percentile?	114	3879	3993	2.85%
Systolic Blood Pressure > 95th Percentile?	106	3887	3993	2.65%
Diastolic Blood Pressure > 95th Percentile?	106	3887	3993	2.65%

Table 8 Simulation results for "At risk for overweight" but not "Overweight" (85th < quetelet index < 95th) children ages 5 to 10 years

Simulation results for "At risk for overweight" but not "Overweight" (85th < quetelet index < 95th) children ages 5 to 10 years				
	Yes	**No**	**Total**	**Percent**
Total Cholesterol > 200 mg/dL?	114	510	624	18.27%
Triglycerides > 130 mg/dL?	66	558	624	10.58%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	100	524	624	16.03%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	48	576	624	7.69%
Fasting Insulin > 95th Percentile?	72	552	624	11.54%
Systolic Blood Pressure > 95th Percentile?	91	533	624	14.58%
Diastolic Blood Pressure > 95th Percentile?	62	562	624	9.94%

Table 9 Simulation results for "Overweight" (quetelet index > 95th) children ages 5 to 10 years

Simulation results for "Overweight" (quetelet index > 95th) children ages 5 to 10 years				
	Yes	**No**	**Total**	**Percent**
Total Cholesterol > 200 mg/dL?	76	307	383	19.84%
Triglycerides > 130 mg/dL?	55	328	383	14.36%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	73	310	383	19.06%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	53	330	383	13.84%
Fasting Insulin > 95th Percentile?	58	325	383	15.14%
Systolic Blood Pressure > 95th Percentile?	62	321	383	16.19%
Diastolic Blood Pressure > 95th Percentile?	44	339	383	11.49%

A comparison of Tables 6 through 9, concludes that the percentage of children "at risk" for various cardiovascular risk factors increased with each increasing level of severity in weight status. What's more, a status of "healthy weight" showed significant reduction in occurrence of cardiovascular risk factors.

Tables 10 and 11 provide a summary of the results from the simulation model and the Bogalusa Heart Study. A comparison of Tables 16 and 17 provides an example of the level of variation experienced in computer simulation.

Table 10 Simulation results for children ages 5 to 10 years

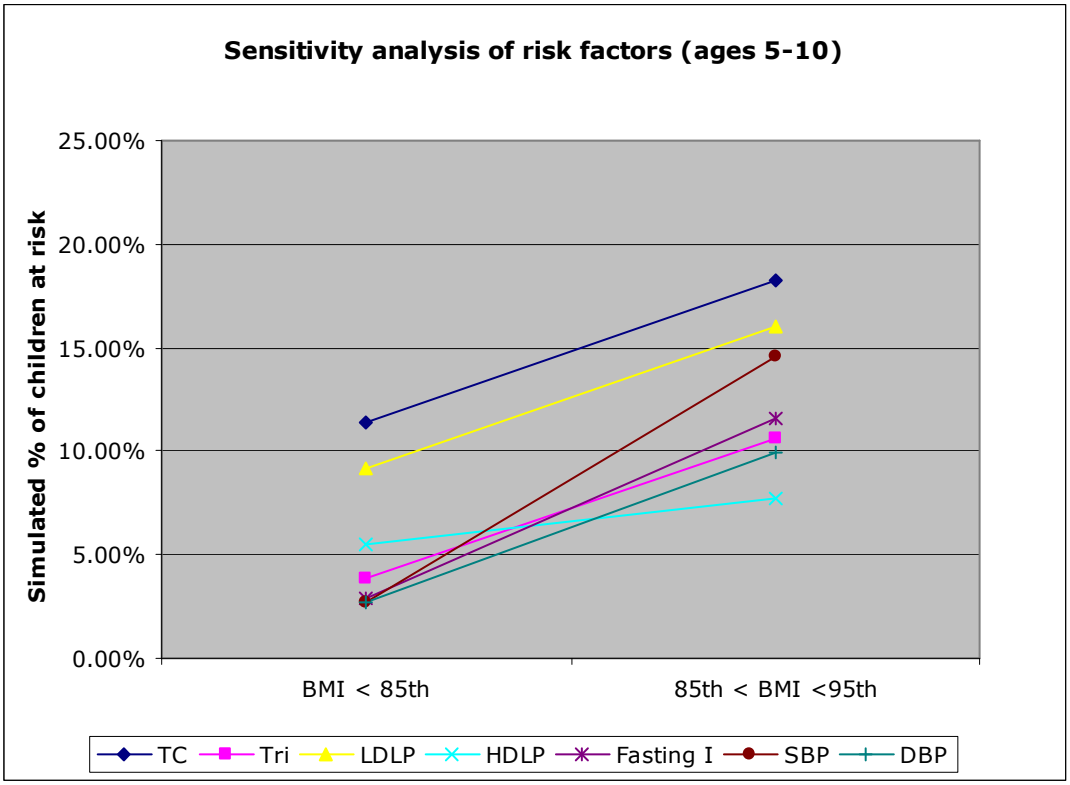
Simulation results for children ages 5 to 10 years				
	All BMI	**BMI<85th**	**85th<BMI<95th**	**BMI>95th**
Total Cholesterol > 200 mg/dL?	12.90%	11.39%	18.27%	19.84%
Triglycerides > 130 mg/dL?	5.52%	3.88%	10.58%	14.36%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	10.80%	9.19%	16.03%	19.06%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	6.44%	5.53%	7.69%	13.84%
Fasting Insulin > 95th Percentile?	4.88%	2.85%	11.54%	15.14%
Systolic Blood Pressure > 95th Percentile?	5.18%	2.65%	14.58%	16.19%
Diastolic Blood Pressure > 95th Percentile?	4.24%	2.65%	9.94%	11.49%

Table 11 Bogalusa Heart Study results for children ages 5 to 10 years

Bogalusa Heart Study results for children ages 5 to 10 years				
	All BMI	**BMI<85th**	**85th<BMI<95th**	**BMI>95th**
Total Cholesterol > 200 mg/dL?	12.01%	10.04%	18.00%	21.31%
Triglycerides > 130 mg/dL?	5.25%	3.04%	10.00%	17.91%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	10.66%	8.52%	18.00%	19.91%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	6.43%	5.16%	8.00%	14.91%
Fasting Insulin > 95th Percentile?	4.53%	2.40%	4.00%	22.22%
Systolic Blood Pressure > 95th Percentile?	5.06%	3.03%	7.00%	19.19%
Diastolic Blood Pressure > 95th Percentile?	4.69%	3.39%	7.00%	12.60%

Utilizing the results from Tables 6 through 9 several implications can be made that are relevant for addressing overweight in children and adolescents in the future. The sensitivity analysis provided in Figures V-1 and V-2 show the risk factors that are most sensitive to weight status. Particularly, Figure V-1 shows the sensitivity of risk factors by healthy weight status (BMI less than 85th percentile) and "at risk of overweight" status (BMI between 85th and 95th percentiles).

Figure V-1 Sensitivity analysis of risk factors by simulated percentage at risk (ages 5-10)



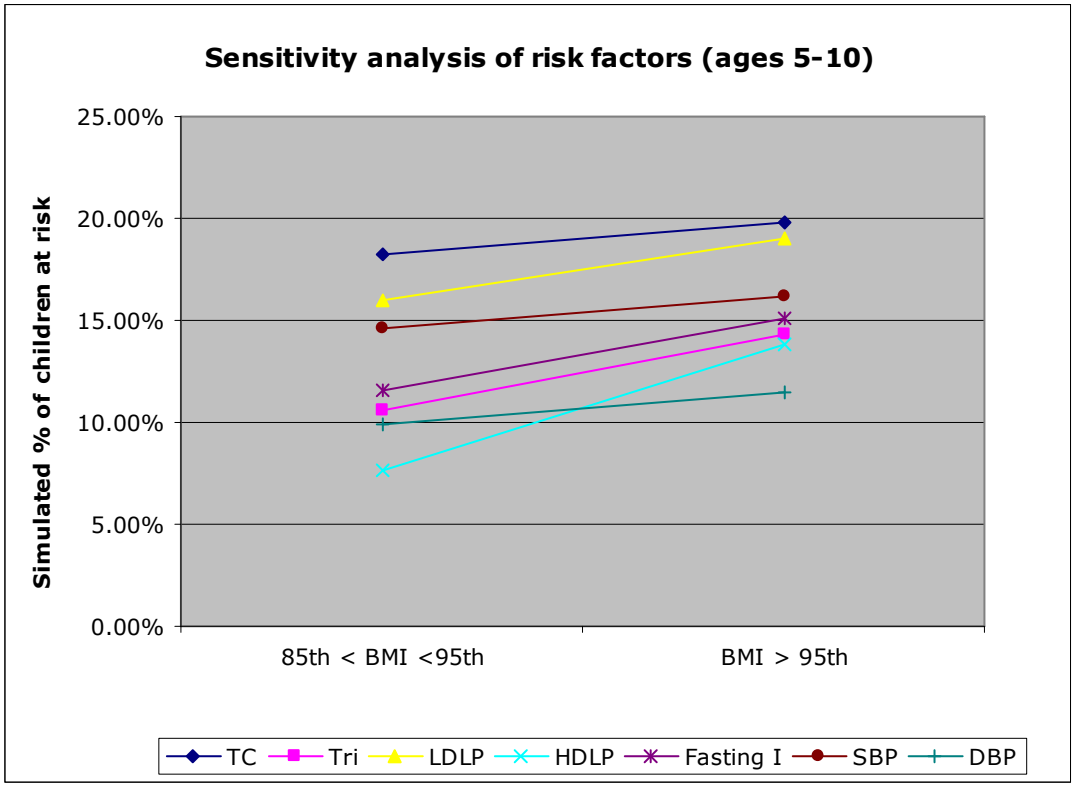
First, the most sensitive risk factor appears to be systolic blood pressure (SBP). This is identified because of the steep slope of the SBP line. Based on this finding, public health professionals may infer that interventions aimed at SBP levels in overweight children are most critical (because of the sensitivity to weight status). However, this assumption should be weighted against the significance that SBP has on specific outcomes such as cardiovascular disease.

Second, risk for total cholesterol (TC) levels has the highest percentages for both "healthy weight" children as well as children with a weight status of "at risk for overweight", but not "overweight". This may indicate the criticality for public health professionals to create interventions for addressing total cholesterol levels in children of all weight statuses. Here again, this decision should be weighed against the significance

of total cholesterol on specific outcomes such as cardiovascular disease. However, it is clear that Monte Carlo simulation in conjunction with tools such as sensitivity analysis provide the means for gaining insight into the relationships between cardiovascular risk factors and child and adolescent BMI.

Next, a similar sensitivity analysis is performed to examine the sensitivity of risk factors by weight status for "at risk of overweight" (BMI between 85th and 95th percentiles) and "overweight" (BMI greater than 95th percentile) children.

Figure V-2 Sensitivity analysis of risk factors by simulated percentage at risk (ages 5-10)



From this graph, it is interesting to note that high-density lipoprotein cholesterol (HDLP) has the smallest slope value in Figure V-1 but has the steepest slope in Figure V-2. This may indicate a need for creating interventions aimed at aimed at improving HDLP levels in children who have a BMI greater than the 95th percentile.

Simulation results for adolescents 11 to 17 years of age.

The results from the second simulation model (Figure IV-4) for adolescents ages 11 to 17 are provided in Tables 12 through 15. Total number of occurrences and percentages are shown for all trials (Table 12), adolescents with BMI < 85th percentile (Table 13), adolescents with BMI between the 85th and 95th percentiles (Table 14), and adolescents with BMI > 95th percentile (Table 15).

Table 12 Simulation results for all adolescents ages 11 to 17 years

Simulation results for all adolescents ages 11 to 17 years				
	Yes	**No**	**Total**	**Percent**
Adolescents "at risk for overweight" but who are not "overweight"	772	4228	5000	15.44%
Adolescents who are "overweight"	569	4431	5000	11.38%
Total Cholesterol > 200 mg/dL?	463	4537	5000	9.26%
Triglycerides > 130 mg/dL?	447	4553	5000	8.94%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	403	4597	5000	8.06%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	548	4452	5000	10.96%
Fasting Insulin > 95th Percentile?	241	4759	5000	4.82%
Systolic Blood Pressure > 95th Percentile?	233	4767	5000	4.66%
Diastolic Blood Pressure > 95th Percentile?	250	4750	5000	5.00%

Table 13 Simulation results for healthy weight (quetelet index < 85th) adolescents ages 11 to 17 years

Simulation results for healthy weight (quetelet index < 85th) adolescents ages 11 to 17 years				
	Yes	**No**	**Total**	**Percent**
Total Cholesterol > 200 mg/dL?	260	3399	3659	7.11%
Triglycerides > 130 mg/dL?	191	3468	3659	5.22%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	199	3460	3659	5.44%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	334	3325	3659	9.13%
Fasting Insulin > 95th Percentile?	64	3595	3659	1.75%
Systolic Blood Pressure > 95th Percentile?	139	3520	3659	3.80%
Diastolic Blood Pressure > 95th Percentile?	173	3486	3659	4.73%

Table 14 Simulation results for "At risk for overweight" but not "Overweight" (85th < quetelet index < 95th) adolescents ages 11 to 17 years

Simulation results for "At risk for overweight" but not "Overweight" (85th < quetelet index < 95th) adolescents ages 11 to 17 years				
	Yes	**No**	**Total**	**Percent**
Total Cholesterol > 200 mg/dL?	101	671	772	13.08%
Triglycerides > 130 mg/dL?	129	643	772	16.71%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	110	662	772	14.25%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	123	649	772	15.93%
Fasting Insulin > 95th Percentile?	78	694	772	10.10%
Systolic Blood Pressure > 95th Percentile?	50	722	772	6.48%
Diastolic Blood Pressure > 95th Percentile?	37	735	772	4.79%

Table 15 Simulation results for "Overweight" (quetelet index > 95th) adolescents ages 11 to 17 years

Simulation results for "Overweight" (quetelet index > 95th) adolescents ages 11 to 17 years				
	Yes	**No**	**Total**	**Percent**
Total Cholesterol > 200 mg/dL?	102	467	569	17.93%
Triglycerides > 130 mg/dL?	127	442	569	22.32%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	94	475	569	16.52%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	91	478	569	15.99%
Fasting Insulin > 95th Percentile?	99	470	569	17.40%
Systolic Blood Pressure > 95th Percentile?	44	525	569	7.73%
Diastolic Blood Pressure > 95th Percentile?	40	529	569	7.03%

A comparison of Tables 12 through 15, concludes that the percentage of adolescents "at risk" for various cardiovascular risk factors increased with each increasing level of severity in weight status. Again, a status of "healthy weight" showed significant reduction in occurrence of cardiovascular risk factors.

Tables 16 and 17 provide a summary of the results from the simulation model and the Bogalusa Heart Study. A comparison of Tables 16 and 17 provides an example of the level of variation experienced in computer simulation.

Table 16 Simulation results for adolescents ages 11 to 17 years

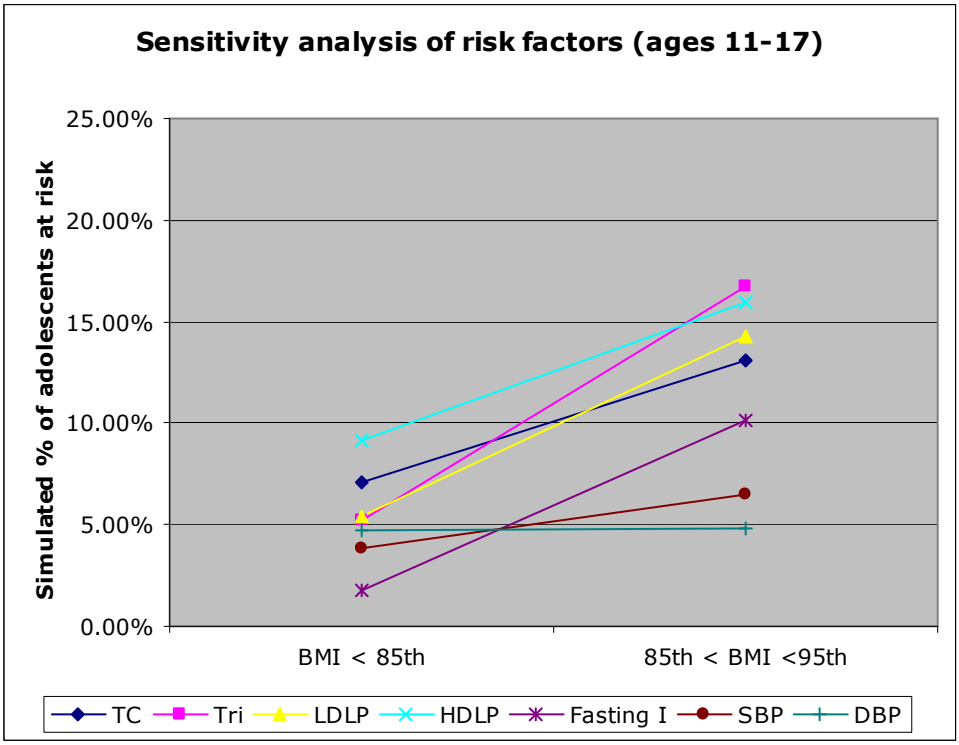
Simulation results for adolescents ages 11 to 17 years				
	All BMI	**BMI<85th**	**85th<BMI<95th**	**BMI>95th**
Total Cholesterol > 200 mg/dL?	9.26%	7.11%	13.08%	17.93%
Triglycerides > 130 mg/dL?	8.94%	5.22%	16.71%	22.32%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	8.06%	5.44%	14.25%	16.52%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	10.96%	9.13%	15.93%	15.99%
Fasting Insulin > 95th Percentile?	4.82%	1.75%	10.10%	17.40%
Systolic Blood Pressure > 95th Percentile?	4.66%	3.80%	6.48%	7.73%
Diastolic Blood Pressure > 95th Percentile?	5.00%	4.73%	4.79%	7.03%

Table 17 Bogalusa Heart Study results for adolescents ages 11 to 17 years

Bogalusa Heart Study results for adolescents ages 11 to 17 years				
	All BMI	**BMI<85th**	**85th<BMI<95th**	**BMI>95th**
Total Cholesterol > 200 mg/dL?	9.00%	6.74%	15.00%	16.68%
Triglycerides > 130 mg/dL?	8.10%	4.45%	12.00%	27.36%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	7.83%	5.33%	13.00%	18.02%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	10.78%	8.88%	14.00%	19.34%
Fasting Insulin > 95th Percentile?	4.27%	1.75%	5.00%	20.03%
Systolic Blood Pressure > 95th Percentile?	5.00%	4.03%	7.00%	9.01%
Diastolic Blood Pressure > 95th Percentile?	4.92%	4.71%	4.00%	7.34%

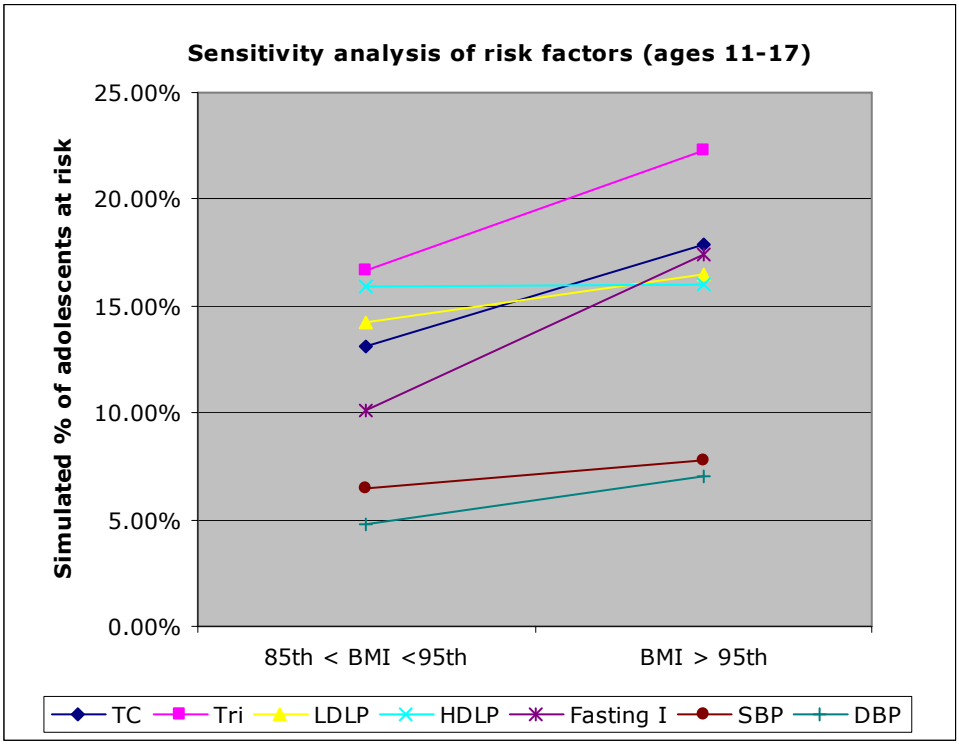
Figure V-3 provides a sensitivity analysis of risk factors by healthy weight status (BMI less than 85th percentile) and "at risk of overweight" status (BMI between 85th and 95th percentiles) for ages 11-17.

Figure V-3 Sensitivity analysis of risk factors by simulated percentage at risk (ages 11-17)



From this graph, triglycerides had not only the steepest slope but also the highest percentage of at risk adolescents between the ages of 11 to 17 when moving from a status of "health weight" to "at risk for overweight" but not 'overweight". Based on this finding, public health professionals may need to focus more attention on intervention for reducing triglyceride levels in adolescents between the ages of 11 to 17.

Figure V-4 Sensitivity analysis of risk factors by simulated percentage at risk (ages 11-17)



Based on the sensitivity analysis in Figure V-4, triglycerides, again, have the highest percentage of "at risk" 11 to 17 year olds. It is also interesting to note that the percentage of adolescents at risk for High-Density Lipoprotein Cholesterol (HDLC) has almost no change when moving from children who are "at risk of overweight" but not "overweight' to a status of "overweight". This may indicate an opportunity for public health professionals to focus resources on interventions that target other risk factors for children. However, this decision should only be made after considering variables such as the weighted impact HDLC has on outcomes such as cardiovascular disease when compared to other risk factors.

Multiple risk factor analysis

Utilizing the results from the previous section, a multiple risk factor analysis is performed to illustrate how Monte Carlo simulation can provide insight into co-existence of risk factors as a result of BMI. Analysis is performed separately for children and adolescents.

Total number of co-existing risk factors for children 5 to 10 years of age

Graphs showing frequency by number of co-existing cardiovascular risk factors are presented separately for all children ages 5 to 10 (Figure V-5), children of "healthy weight" ages 5 to 10 (Figure V-6), children "at risk for overweight" ages 5 to 10 (Figure V-7), and "overweight" children ages 5 to 10 (Figure V-8). It is important to note that each graph utilizes a different scale for the y-axis. Additionally, each graph utilizes a different sample size making the percentage of children with multiple risk factors the most significant measure of comparison.

Figure V-5 Total number of co-existing risk factors for children ages 5 to 10 (combined weight status n=5,000)

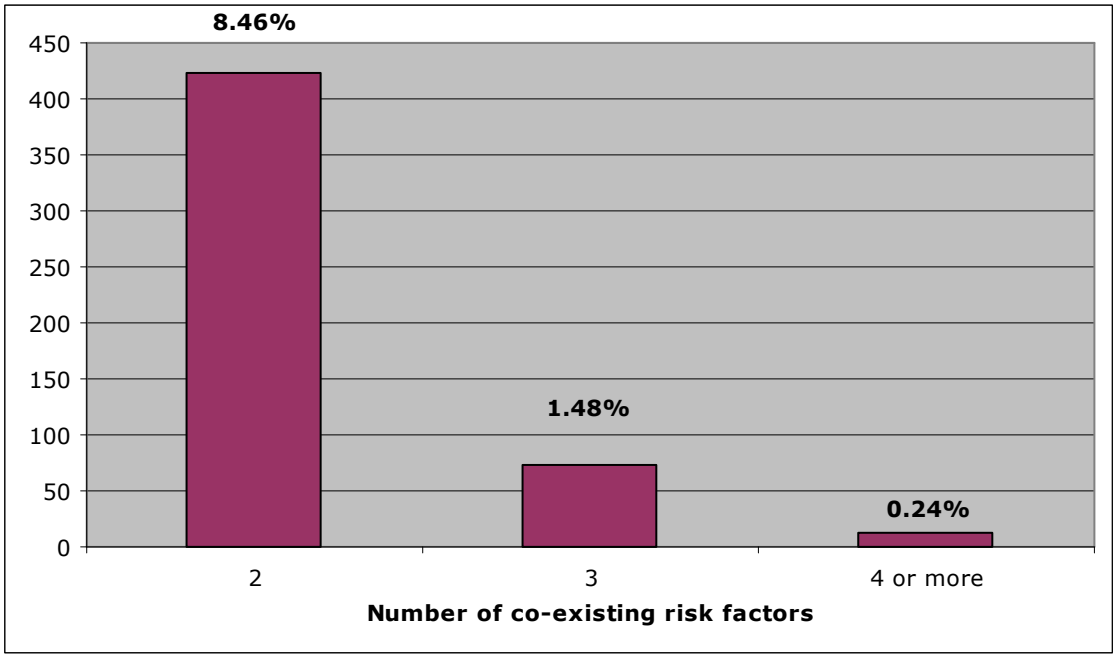


Figure V-6 Total number of co-existing risk factors for children ages 5 to 10 who are not "at risk for overweight" or "overweight" (n=3993)

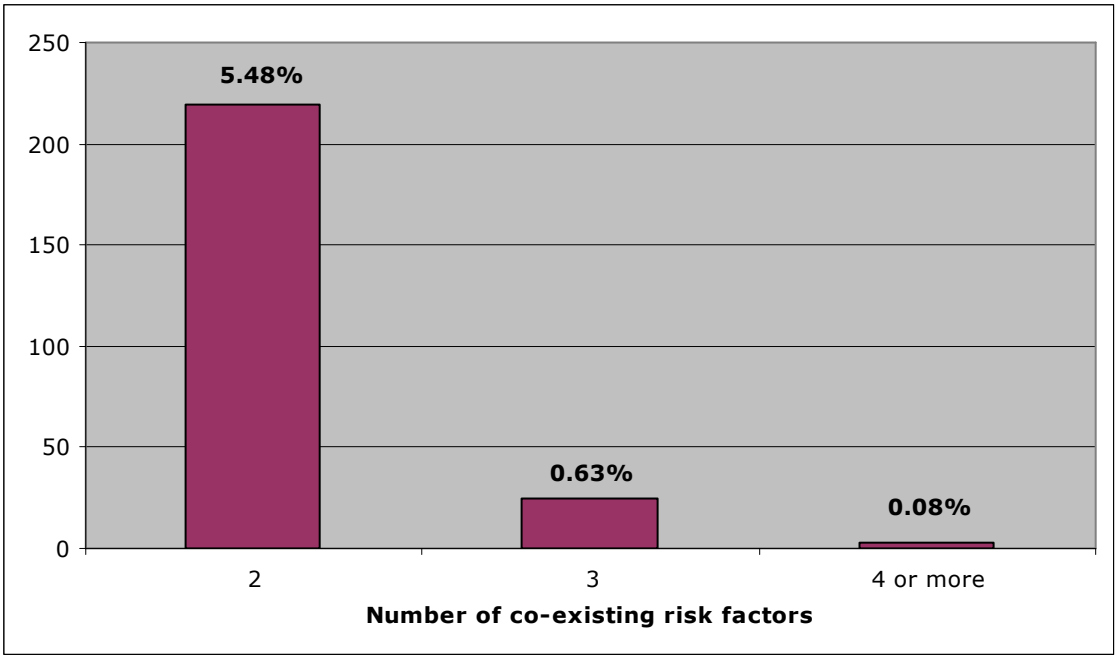


Figure V-7 Total number of co-existing risk factors for children "at risk for overweight" but who are not "overweight" ages 5 to 10 (n=624)

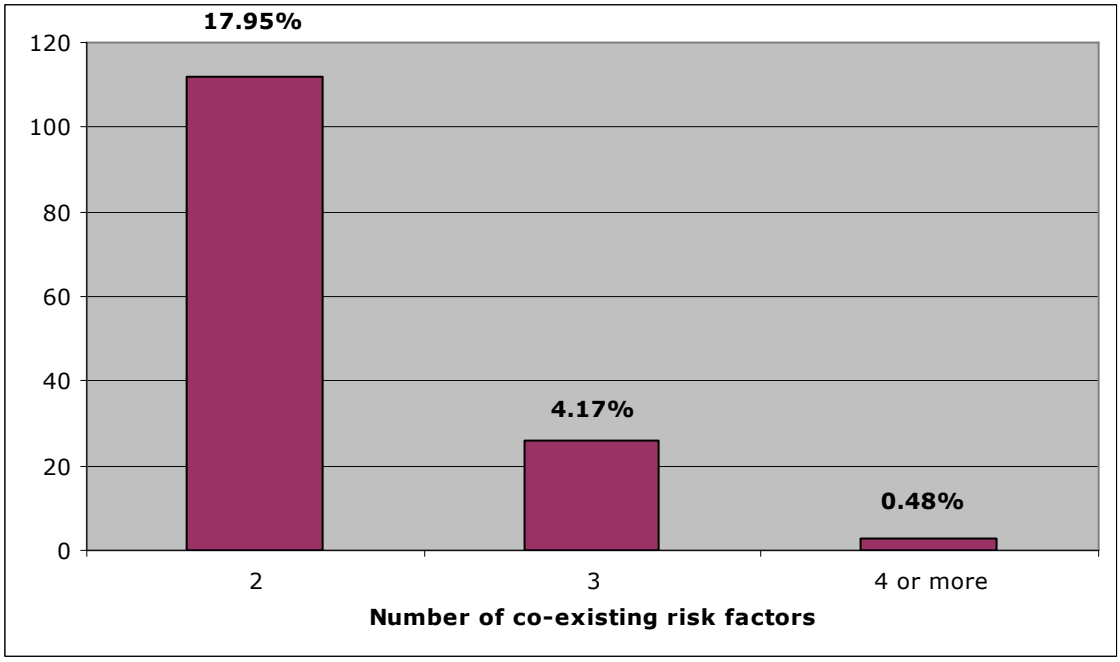
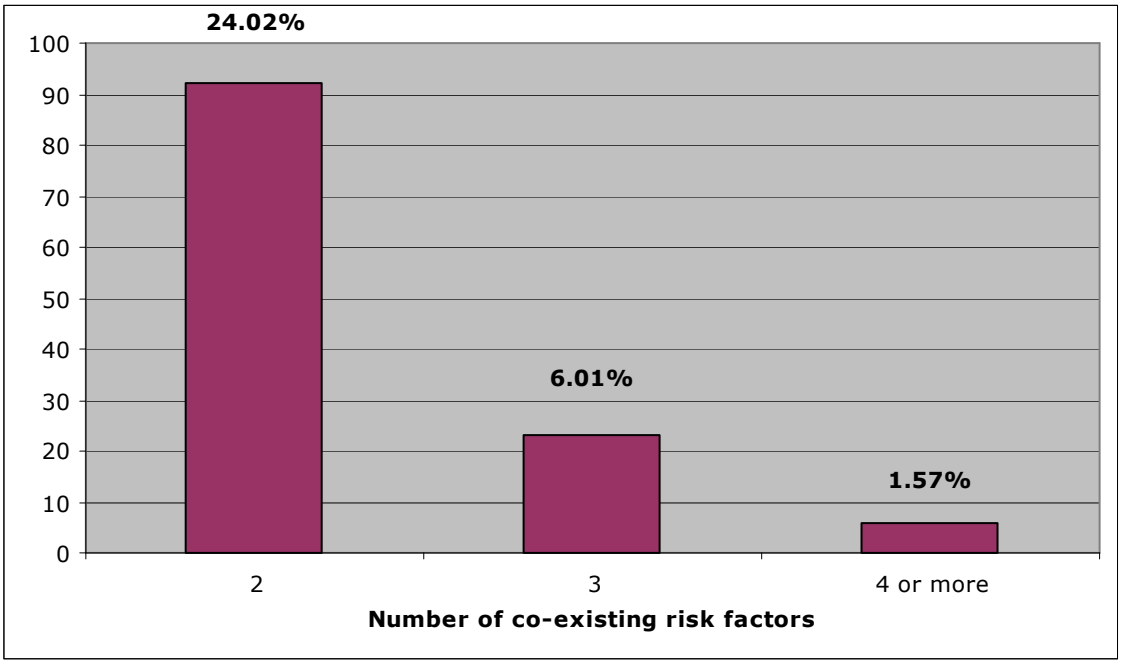


Figure V-8 Total number of co-existing risk factors for children who are "overweight" ages 5 to 10 (n=383)



After comparing Figures V-5 through V-8, the proportion of children with co-existing risk factors increased with each increasing level of severity in weight status. What's more, a status of "healthy weight" showed significant reduction in occurrence of cardiovascular risk factors.

Total number of co-existing risk factors for children 11 to 17 years of age.

Graphs showing frequency by number of co-existing cardiovascular risk factors are presented separately for all adolescents ages 11 to 17 (Figure V-9), adolescents of "healthy weight" ages 11 to 17 (Figure V-10), adolescents "at risk for overweight" ages 11 to 17 (Figure V-11), and "overweight" adolescents ages 11 to 17 (Figure V-12). It is important to note that each graph utilizes a different scale for the y-axis. Additionally, each graph utilizes a different sample size making the percentage of children with multiple risk factors the most significant measure of comparison.

Figure V-9 Total number of co-existing risk factors for adolescents ages 11 to 17 (combined weight status n=5,000)

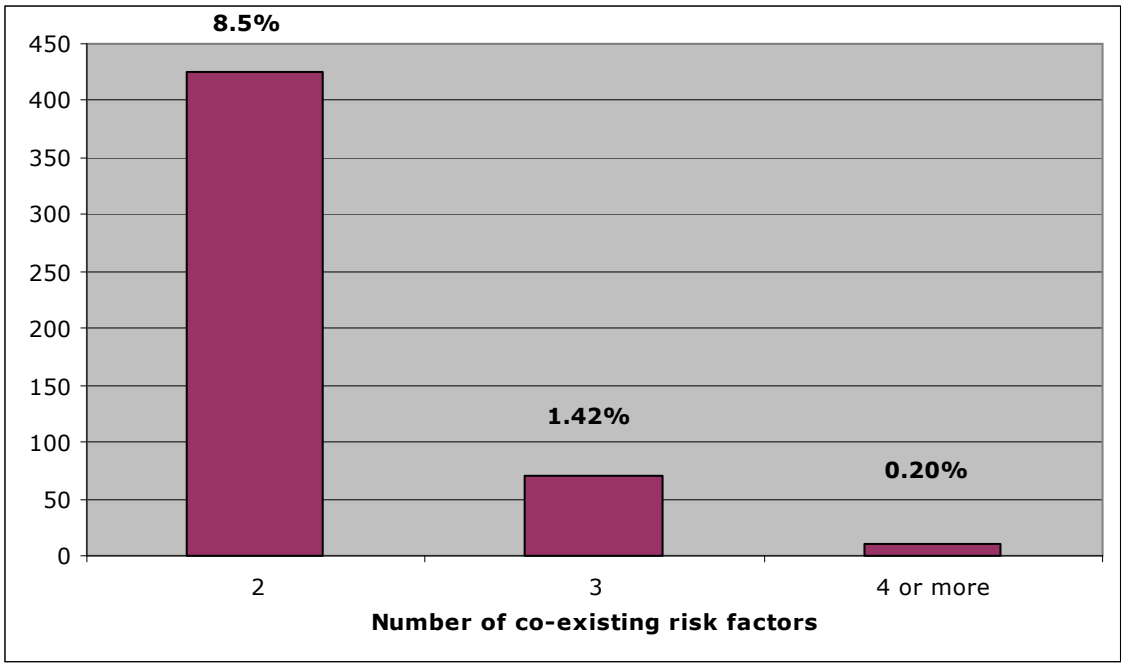


Figure V-10 Total number of coexisting risk factors for adolescents ages 11 to 17 who are not "at risk for overweight" or "overweight" (n=3659)

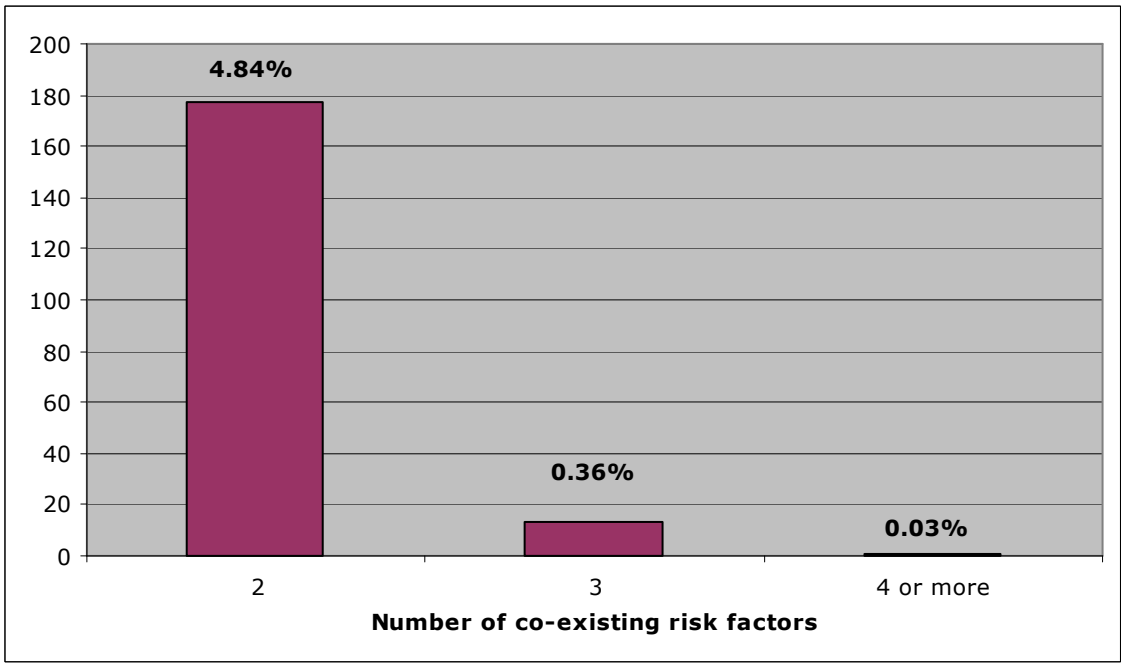


Figure V-11 Total number of coexisting risk factors for adolescents "at risk for overweight" but who are not "overweight" ages 11 to 17 (n=772)

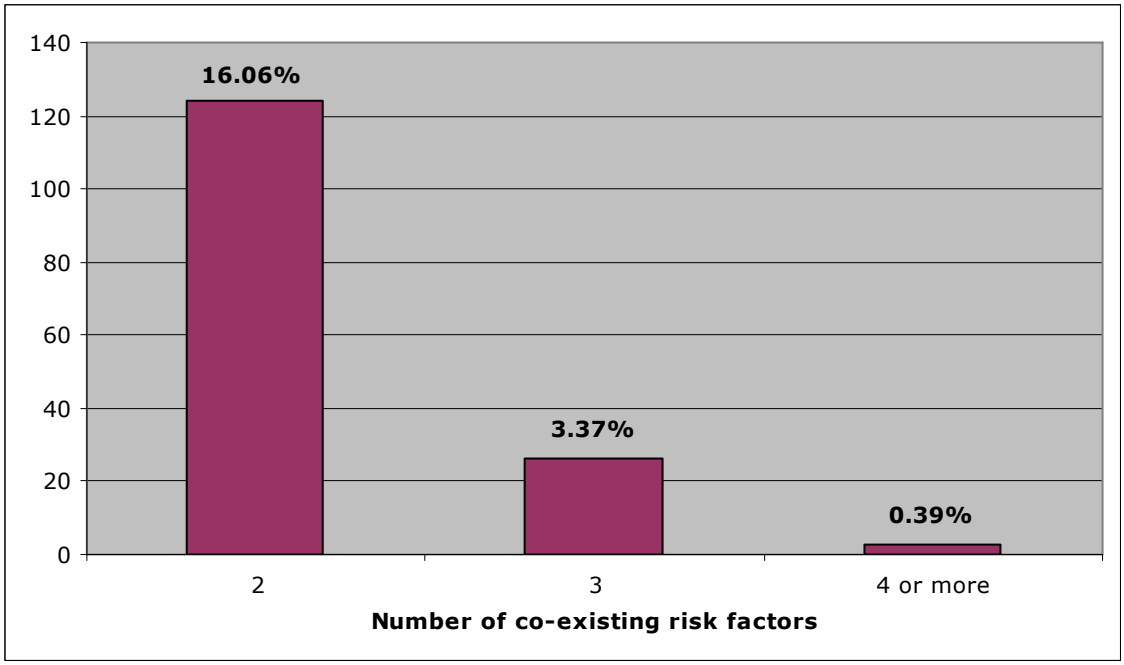
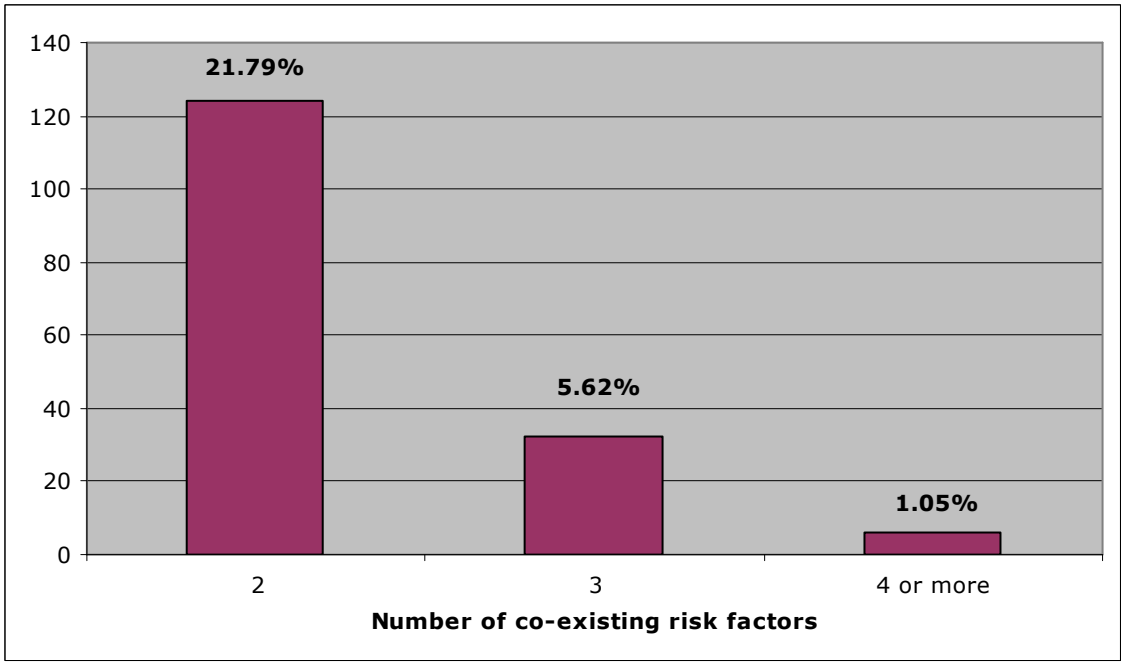


Figure V-12 Total number of coexisting risk factors for adolescents who are "overweight" ages 11 to 17 (n=569)



After comparing Figures 7-5 through 7-8, the proportion of adolescents with co-existing risk factors increased with each increasing level of severity in weight status. Again, a status of "healthy weight" showed significant reduction in occurrence of cardiovascular risk factors.

Changes in risk factors due to controlled BMI

This next section examines how cardiovascular risk factors in children and adolescents may change with changes in BMI.

A new model is now constructed assuming that child and adolescent BMI levels return to recommended standards as presented by the CDC growth charts released in May of 2000 (see Appendix A). The new model is modified to predict child and adolescent BMI patterns utilizing a histogram of CDC recommended BMI levels. The model assumes that all relationships between quetelet index and the probabilities of having a specific cardiovascular risk factor will remain as defined within the original model.

Under the revised model (i.e., 2000 distribution), two new simulations are performed of 5,000 Monte Carlo trials.

Results for children 5 to 10 years of age under the 2000 distribution model

The first simulation is performed for children ages 5 to 10. Totals of weight status and individual risk factors are presented separately for all children ages 5 to 10 (Table 18), children of "healthy weight" ages 5 to 10 (Table 19), children "at risk for overweight" ages 5 to 10 (Table 20), and "overweight" children ages 5 to 10 (Table 21).

Table 18 Simulation results for all children ages 5 to 10 years (2000 distribution model)

Simulation results for all children ages 5 to 10 years				
	Yes	**No**	**Total**	**Percent**
Children "at risk for overweight" but who are not "overweight"	486	4514	5000	9.72%
Children who are "overweight"	214	4786	5000	4.28%
Total Cholesterol > 200 mg/dL?	615	4385	5000	12.30%
Triglycerides > 130 mg/dL?	228	4772	5000	4.56%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	512	4488	5000	10.24%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	312	4688	5000	6.24%
Fasting Insulin > 95th Percentile?	190	4810	5000	3.80%
Systolic Blood Pressure > 95th Percentile?	212	4788	5000	4.24%
Diastolic Blood Pressure > 95th Percentile?	219	4781	5000	4.38%

Table 19 Simulation results for healthy weight (quetelet index < 85th) children ages 5 to 10 years (2000 distribution model)

Simulation results for healthy weight (quetelet index < 85th) children ages 5 to 10 years				
	Yes	**No**	**Total**	**Percent**
Total Cholesterol > 200 mg/dL?	474	3826	4300	11.02%
Triglycerides > 130 mg/dL?	140	4160	4300	3.26%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	392	3908	4300	9.12%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	229	4071	4300	5.33%
Fasting Insulin > 95th Percentile?	112	4188	4300	2.60%
Systolic Blood Pressure > 95th Percentile?	125	4175	4300	2.91%
Diastolic Blood Pressure > 95th Percentile?	152	4148	4300	3.53%

Table 20 Simulation results for "At risk for overweight" but not "Overweight" (85th < quetelet index < 95th) children ages 5 to 10 years (2000 distribution model)

Simulation results for "At risk for overweight" but not "Overweight" (85th < quetelet index < 95th) children ages 5 to 10 years				
	Yes	**No**	**Total**	**Percent**
Total Cholesterol > 200 mg/dL?	88	398	486	18.11%
Triglycerides > 130 mg/dL?	54	432	486	11.11%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	86	400	486	17.70%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	58	428	486	11.93%
Fasting Insulin > 95th Percentile?	49	437	486	10.08%
Systolic Blood Pressure > 95th Percentile?	56	430	486	11.52%
Diastolic Blood Pressure > 95th Percentile?	39	447	486	8.02%

Table 21 Simulation results for "Overweight" (quetelet index > 95th) children ages 5 to 10 years (2000 distribution model)

Simulation results for "Overweight" (quetelet index > 95th) children ages 5 to 10 years				
	Yes	**No**	**Total**	**Percent**
Total Cholesterol > 200 mg/dL?	53	161	214	24.77%
Triglycerides > 130 mg/dL?	34	180	214	15.89%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	34	180	214	15.89%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	25	189	214	11.68%
Fasting Insulin > 95th Percentile?	29	185	214	13.55%
Systolic Blood Pressure > 95th Percentile?	31	183	214	14.49%
Diastolic Blood Pressure > 95th Percentile?	28	186	214	13.08%

As was expected, a comparison of Tables 18 through 21 conclude that the percentage of children “at risk” for various cardiovascular risk factors increased with each increasing level of severity in weight status. Sensitivity for any particular risk factor may be assessed by comparing the degree of change between original and revised models. Figures V-13 through V-15 show side-by-side comparisons to illustrate the impact of reduced BMI on weight status, total cholesterol and co-existence of three cardiovascular risk factors. Graphs for each specific risk factor as well as greater breakdowns in evaluating the co-existence of risk factors for each age group are available in Appendix F.

Figure V-13 Simulation comparison- Children ages 5 to 10 by weight status

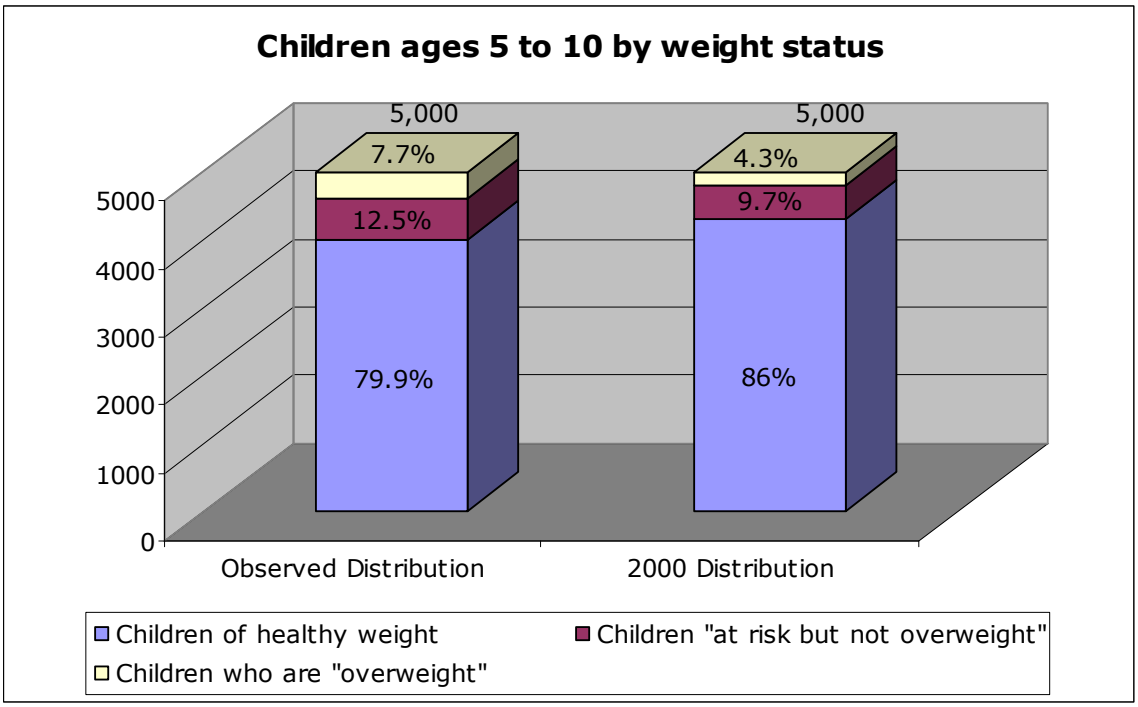


Figure V-14 Simulation comparison- Children ages 5 to 10 w/ total cholesterol > 200 mg/dL

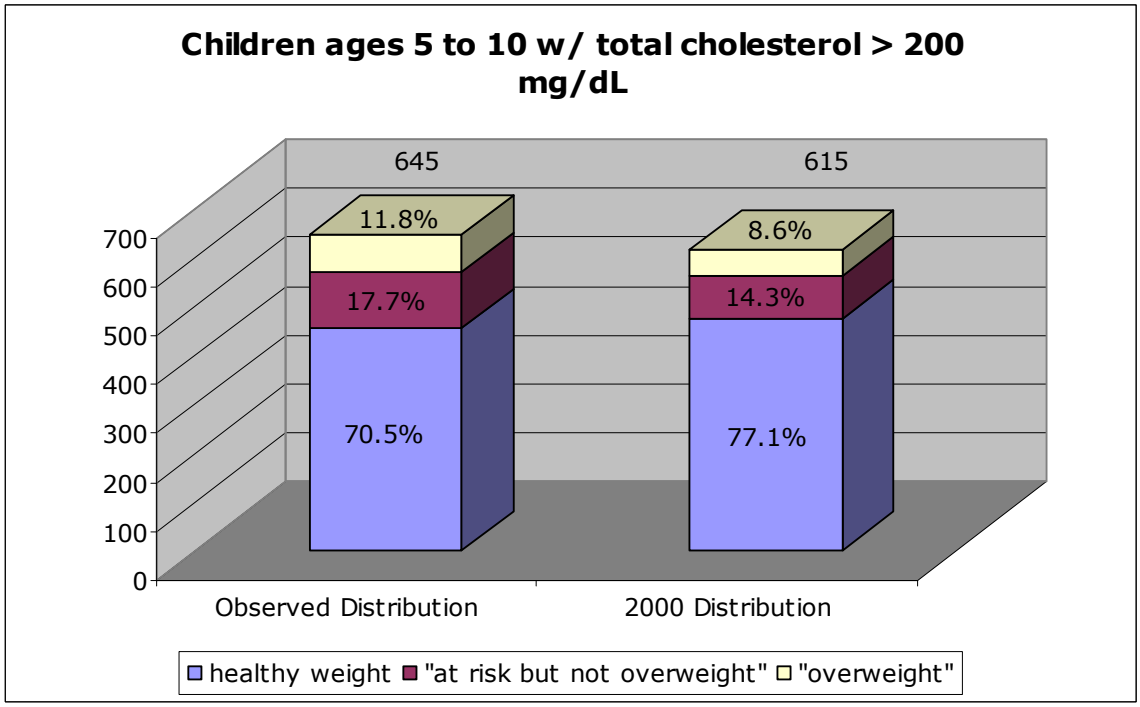
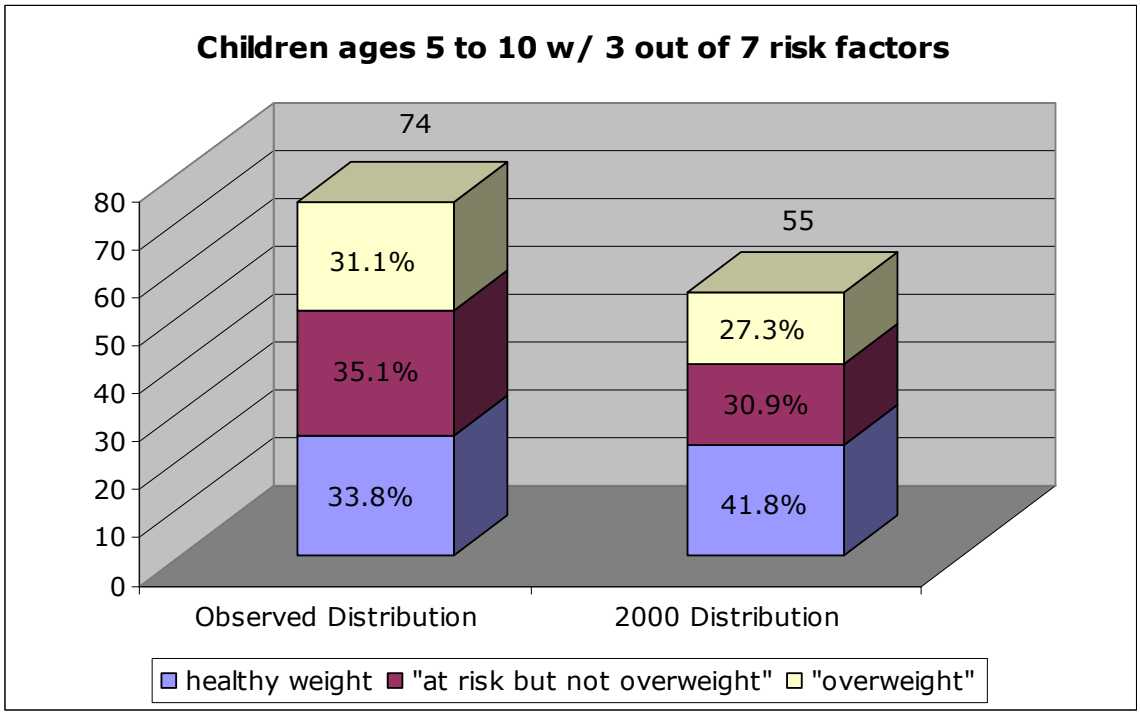


Figure V-15 Simulation comparison- Children ages 5 to 10 w/ 3 out of 7 risk factors



Results for adolescents 11 to 17 years of age under the 2000 distribution model

The next simulation is performed for adolescents ages 11 to 17. Totals of weight status and individual risk factors are presented separately for all adolescents ages 11 to 17 (Table 22), adolescents of "healthy weight" ages 11 to 17 (Table 23), adolescents "at risk for overweight" ages 11 to 17 (Table 24), and "overweight" adolescents ages 11 to 17 (Table 25).

Table 22 Simulation results for all children ages 11 to 17 years (2000 distribution model)

Simulation results for all adolescents ages 11 to 17 years				
	Yes	**No**	**Total**	**Percent**
Adolescents "at risk for overweight" but who are not "overweight"	504	4496	5000	10.08%
Children who are "overweight"	212	4788	5000	4.24%
Total Cholesterol > 200 mg/dL?	371	4629	5000	7.42%
Triglycerides > 130 mg/dL?	317	4683	5000	6.34%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	348	4652	5000	6.96%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	525	4475	5000	10.50%
Fasting Insulin > 95th Percentile?	194	4806	5000	3.88%
Systolic Blood Pressure > 95th Percentile?	219	4781	5000	4.38%
Diastolic Blood Pressure > 95th Percentile?	217	4783	5000	4.34%

Table 23 Simulation results for healthy weight (quetelet index < 85th) children ages 11 to 17 years (2000 distribution model)

Simulation results for healthy weight (quetelet index < 85th) adolescents ages 11 to 17 years				
	Yes	**No**	**Total**	**Percent**
Total Cholesterol > 200 mg/dL?	288	3994	4282	6.73%
Triglycerides > 130 mg/dL?	171	4111	4282	3.99%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	231	4051	4282	5.39%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	399	3883	4282	9.32%
Fasting Insulin > 95th Percentile?	91	4191	4282	2.13%
Systolic Blood Pressure > 95th Percentile?	160	4122	4282	3.74%
Diastolic Blood Pressure > 95th Percentile?	167	4115	4282	3.90%

Table 24 Simulation results for "At risk for overweight" but not "Overweight" (85th < quetelet index < 95th) children ages 11 to 17 years (2000 distribution model)

Simulation results for "At risk for overweight" but not "Overweight" (85th < quetelet index < 95th) adolescents ages 11 to 17 years				
	Yes	**No**	**Total**	**Percent**
Total Cholesterol > 200 mg/dL?	53	451	504	10.52%
Triglycerides > 130 mg/dL?	106	398	504	21.03%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	72	432	504	14.29%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	88	416	504	17.46%
Fasting Insulin > 95th Percentile?	69	435	504	13.69%
Systolic Blood Pressure > 95th Percentile?	32	472	504	6.35%
Diastolic Blood Pressure > 95th Percentile?	31	473	504	6.15%

Table 25 Simulation results for "Overweight" (quetelet index > 95th) children ages 11 to 17 years (2000 distribution model)

Simulation results for "Overweight" (quetelet index > 95th) adolescents ages 11 to 17 years				
	Yes	**No**	**Total**	**Percent**
Total Cholesterol > 200 mg/dL?	30	184	214	14.02%
Triglycerides > 130 mg/dL?	40	174	214	18.69%
Low-Density Lipoprotein Cholesterol > 130 mg/dL?	45	169	214	21.03%
High-Density Lipoprotein Cholesterol < 35 mg/dL?	38	176	214	17.76%
Fasting Insulin > 95th Percentile?	34	180	214	15.89%
Systolic Blood Pressure > 95th Percentile?	27	187	214	12.62%
Diastolic Blood Pressure > 95th Percentile?	19	195	214	8.88%

Similar to the previous analysis, a comparison of Tables 22 through 25 concludes that the percentage of adolescents “at risk” for various cardiovascular risk factors increased with each increasing level of severity in weight status. Figures V-16 through V-18 show side-by-side comparisons to illustrate the impact of reduced BMI on weight status, total cholesterol and co-existence of three cardiovascular risk factors. Graphs for each specific risk factor as well as greater breakdowns in evaluating the co-existence of risk factors for each age group are available in Appendix F.

Figure V-16 Simulation comparison- Children ages 11 to 17 by weight status

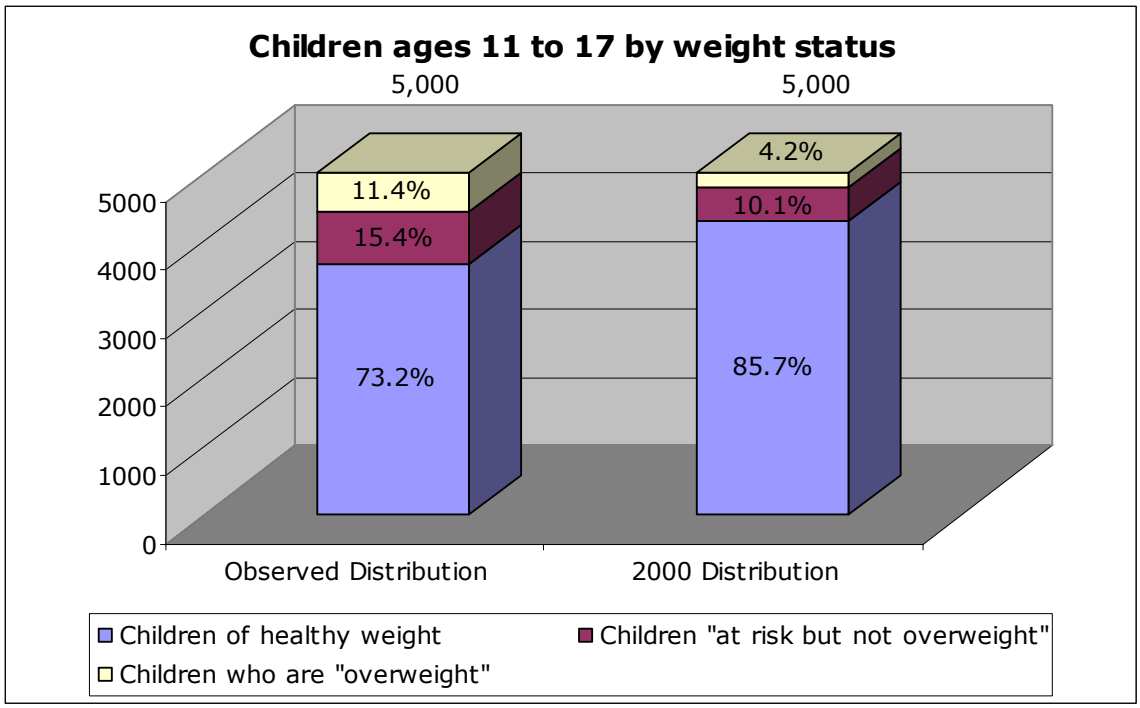


Figure V-17 Simulation comparison- Children ages 11 to 17 w/ total cholesterol > 200 mg/dL

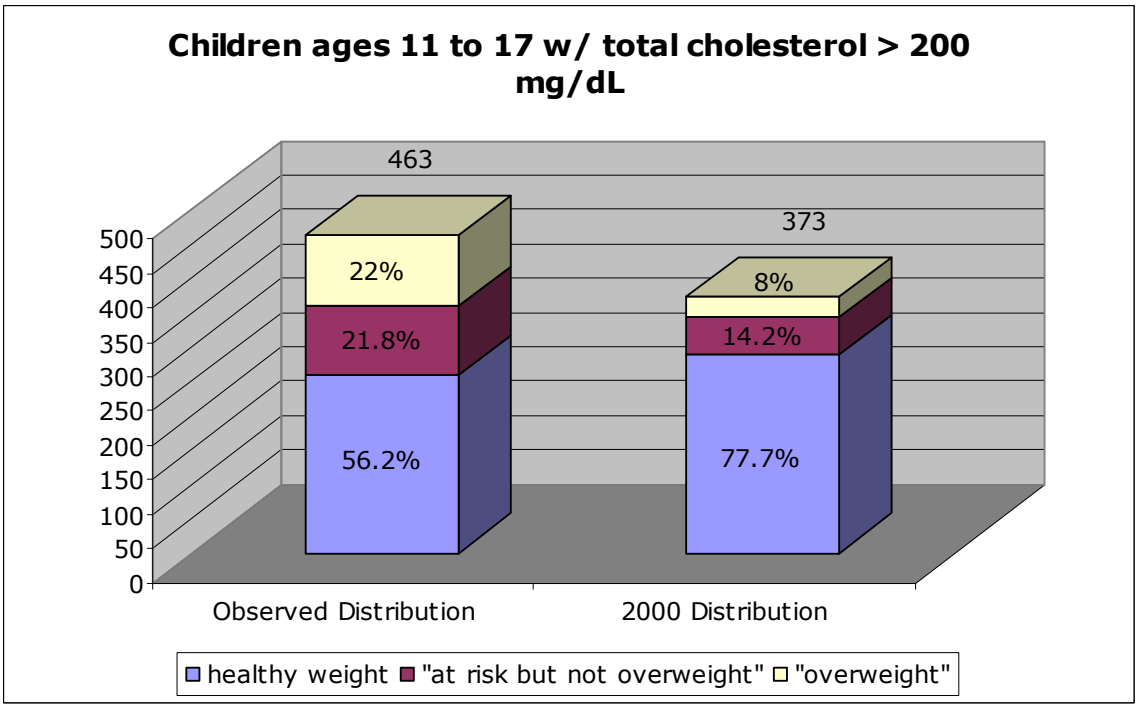
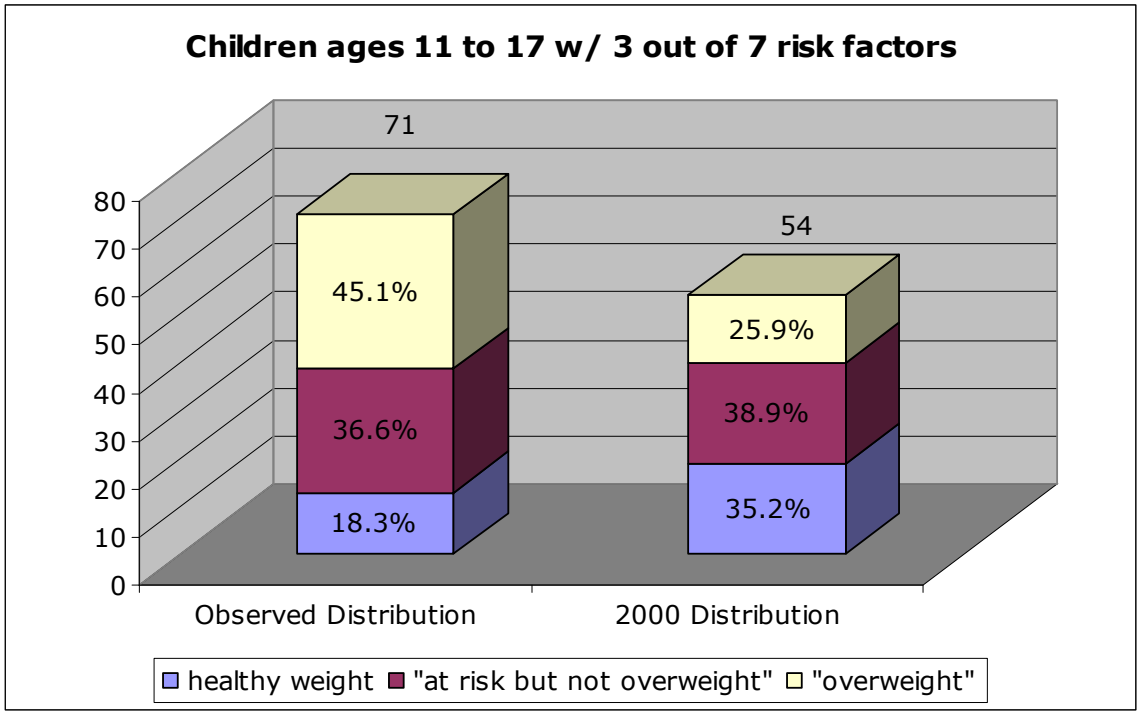


Figure V-18 Simulation comparison- Children ages 11 to 17 w/ 3 out of 7 risk factors



Study limitations and future opportunities

Although simulation is a valuable tool in strategy development, it does present a number of limitations. First and foremost, all simulation models are restricted to the principles of "garbage in: garbage out". A model is only as good as the probabilities used in its design. The model presented in this thesis was designed using probabilities from the Bogalusa Heart Study. It is important to note that the population used in this study comes from a region of the U.S. that is more likely to be at risk for overweight. The potential exists to improve model accuracy by combining data from other studies to create larger data sets and more accurate probabilities.

The study population was limited to 43,000 (1/3 black, 2/3 white) schoolchildren between the ages of 5 and 17 years. Analysis was restricted to individuals who properly fasted and who had recorded values for weight, height, total cholesterol and systolic

blood pressure. The resulting sample was restricted to a sample size of 9,167 schoolchildren between the ages of 5 and 17 years.

Additional limitations include the following:

Accuracy of BMI readings - BMI is a good tool for broad categorization of populations for statistical purposes. That said, BMI does come with limitations. Distortions to this index may be attributed to factors such as fitness level, muscle mass, bone structure, gender and ethnicity.

Sampling error - The model is subject to limitations in population sample sizes and aggregation of data for ages 5-10 and 11-17 years. Additionally, the revised simulation model presented in Chapter V utilizes the same polynomial equations for cardiovascular risk factors derived from the original probabilities obtained through the Bogalusa Heart Study. This generalization may contribute to larger sampling error.

Relationships between risk factors - The model treats each risk factor independently and does not account for the complexities of relationships that exist between risk factors. It is outside the scope of this paper to explain all relationships that may exist between data points.

Regression analysis - The model is limited by the generalizations of calculating trend lines and in using quetelet index ranges for each predicted cardiovascular risk factor.

Trial size - Each Monte Carlo simulation is performed for five iterations of 1,000 trials. Therefore, each simulation is limited to a total of 5,000 trials. This number of trials is assumed sufficient in achieving the Law of Large Numbers. Additionally, each iteration utilizes a different algorithm for generating numbers and therefore achieves greater randomness.

VI. Conclusion

This thesis examines the use of Monte Carlo computer simulation as a tool for assisting organizations in identifying effective strategies for fighting childhood overweight. The goal of this thesis is to help organizations understand the benefits and limitations of computer simulation modeling in predicting cardiovascular risk factors among overweight children and adolescents.

The Monte Carlo computer models presented in Chapter IV (Figures IV-3 and IV-4) assisted in explaining the relationships that exist between BMI and cardiovascular risk factors in children and adolescents. Additionally, a sensitivity analysis was utilized to

determine the risk factors most sensitive to weight status. Utilizing this information public health professionals can better make decisions regarding what interventions should receive attention, funding and resources.

A multiple risk factor analysis also was performed to illustrate how changes in BMI impact changes in co-existing risk factors. Utilizing this methodology public health professionals can quantify the degree by which changes in BMI impact probabilities for co-existing risk factors.

A "what-if" scenario analysis compared how percentages of children and adolescents with cardiovascular risk factors may change if BMI levels were to return to 2000 CDC standards (see Appendix A). Public health professionals may find this analysis helpful when leveraging data produced through pilot programs. Through pilot programs, health professionals may create their own probabilities and customized algorithms for predicting future events. The application of Monte Carlo simulation is not limited to any specific public health problem and/or intervention. Any event that evolves dynamically over time (e.g., disease, injury or behavior) can be assessed as long as data is available for defining a probability distribution. This creates an almost unlimited number of opportunities for applying simulation to public health (e.g. predicting the occurrence of global pandemics, response times to terrorist attacks or spread of HIV/AIDS).

According to Haddix, Teutsch and Corso (2003) Monte Carlo modeling can also be used for "extrapolating costs and health effects beyond the time horizon of a single clinical study. These models can also provide quantitative insight into the relative importance of different components of the screening process and investigate how cost-effectiveness ratios will change if values of key parameters are changed (Haddix,

Teutsch, Corso, 2003, p124). It may be beneficial for future researchers to build financial and resource variables directly into the model for enhanced decision-making ability.

Additionally, future research may assist in expanding the proposed model to include other variables such as caloric burn and/or caloric intake. Likewise, the model may be subdivided to achieve greater granularity by age, sex, race and ethnicity. There really is no limit in refining the model. The more detailed the model the more accurate the results.

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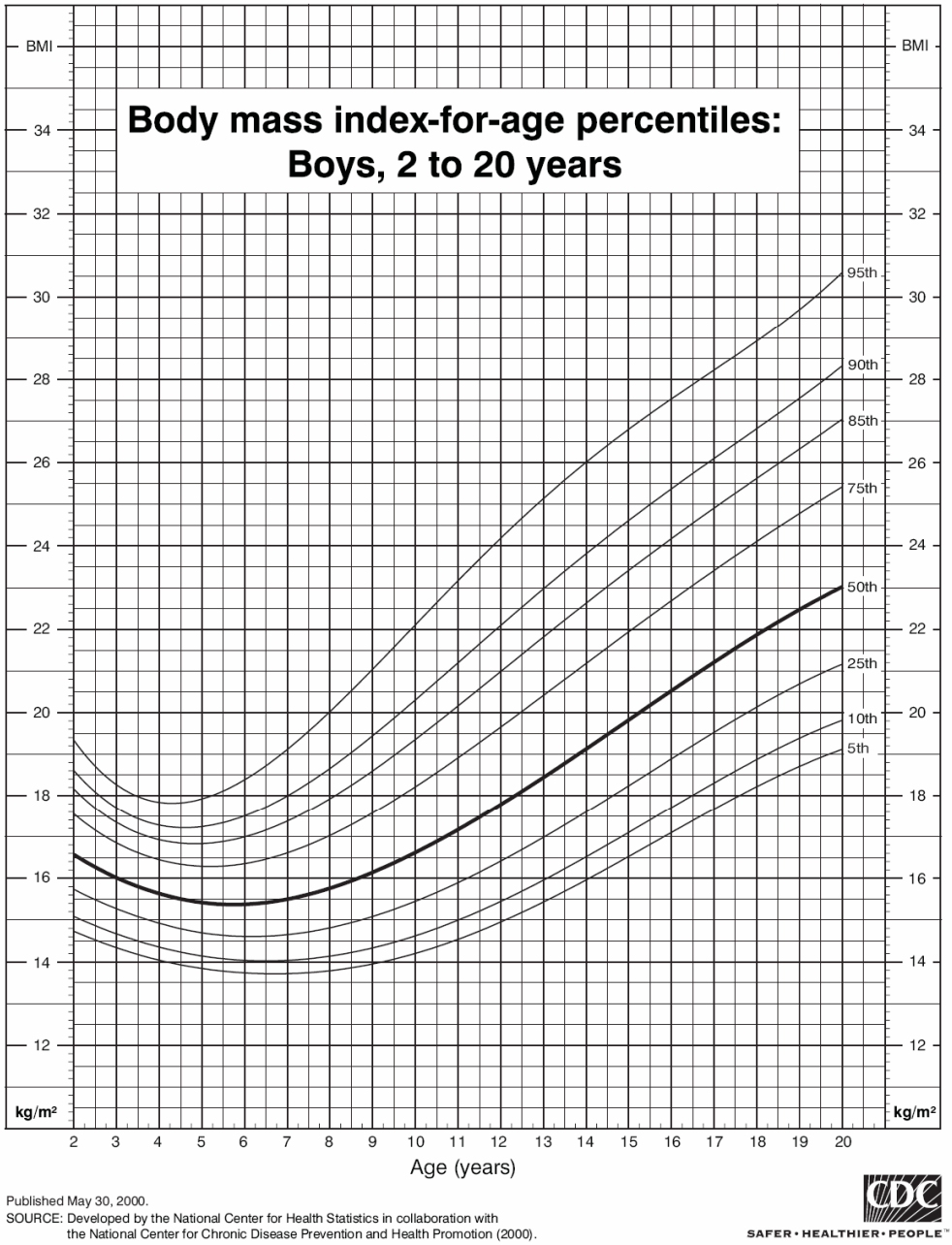
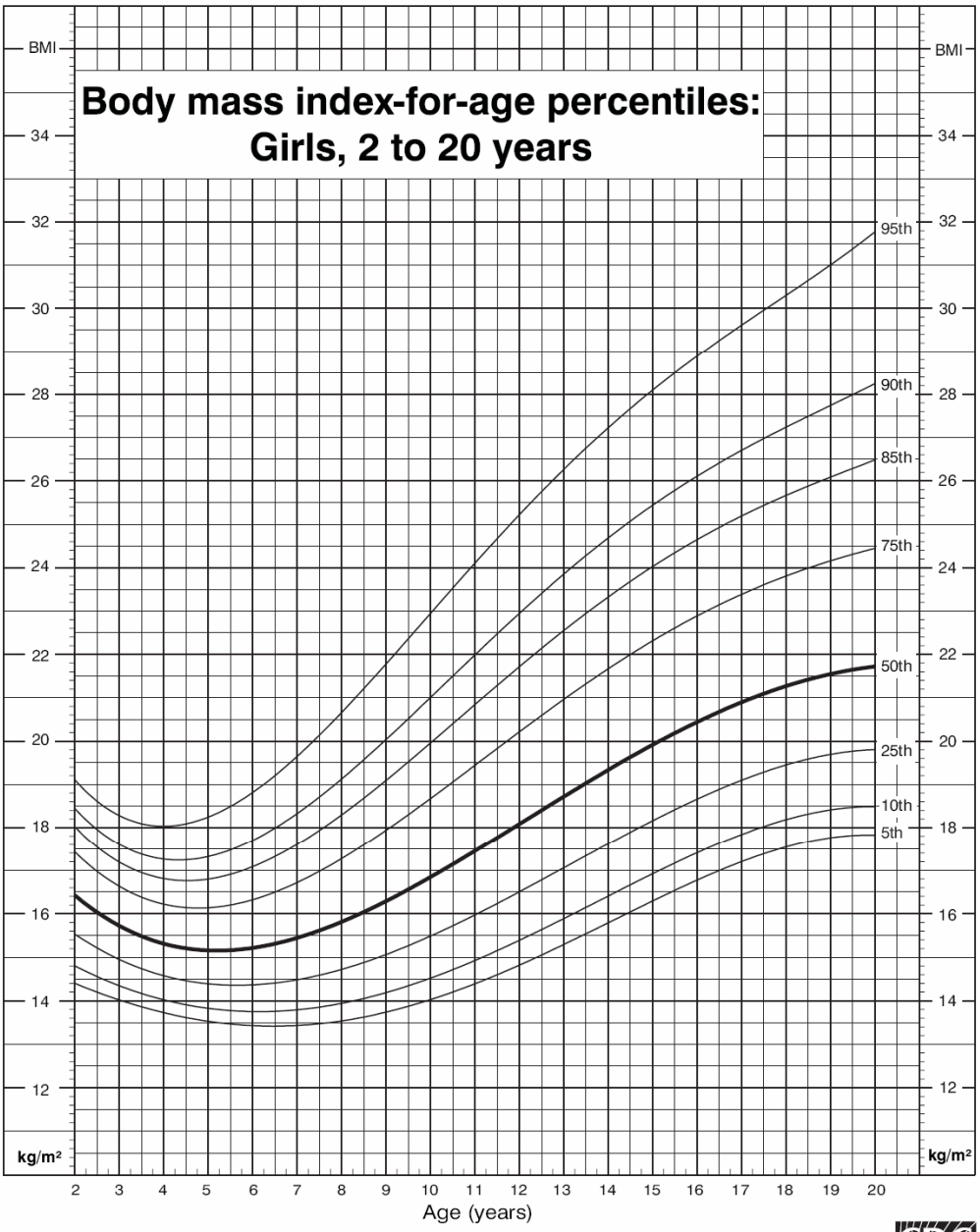
VIII. Appendix A – CDC growth charts: BMI-for-age percentiles



National Center for Health Statistics in collaboration with the National Center for Chronic Disease Prevention and Health Promotion, 2000

CDC Growth Charts: United States



Published May 30, 2000.
SOURCE: Developed by the National Center for Health Statistics in collaboration with the National Center for Chronic Disease Prevention and Health Promotion (2000).

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National Center for Health Statistics in collaboration with the National Center for Chronic Disease Prevention and Health Promotion, 2000

IX. Appendix B – Prevalence of overweight in children and adolescents 1999-2004

	Prevalence of Risk of Overweight or Overweight by Age, % (SE)							
	Male				Female			
	All (2-19 y)	2-5 y	6-11 y	12-19 y	All (2-19 y)	2-5 y	6-11 y	12-19 y
All†								
At risk of overweight or overweight‡								
1999-2000	28.9 (2.7)	21.9 (3.6)	31.9 (4.1)	30.0 (2.2)	27.4 (1.1)	22.2 (2.6)	27.4 (2.4)	30.0 (2.3)
2001-2002	30.6 (1.2)	24.2 (3.0)	32.6 (2.5)	31.5 (2.1)	29.4 (1.6)	22.8 (2.7)	31.6 (3.3)	30.6 (1.6)
2003-2004	34.8 (2.2)	27.3 (2.8)	36.5 (3.1)	36.8 (2.9)	32.4 (2.0)	25.2 (2.8)	38.0 (2.5)	31.7 (3.0)
Overweight§								
1999-2000	14.0 (1.2)	9.5 (2.3)	15.7 (1.8)	14.8 (1.3)	13.8 (1.1)	11.2 (2.5)	14.3 (2.1)	14.8 (1.0)
2001-2002	16.4 (1.0)	10.7 (2.4)	17.5 (1.9)	17.6 (1.3)	14.4 (1.3)	10.5 (1.8)	14.9 (2.4)	15.7 (1.9)
2003-2004	18.2 (1.5)	15.1 (1.7)	19.9 (2.0)	18.3 (1.9)	16.0 (1.4)	12.6 (2.4)	17.6 (1.3)	16.4 (2.3)
Non-Hispanic white								
At risk of overweight or overweight‡								
1999-2000	26.6 (4.3)	21.7 (4.7)	28.5 (6.9)	27.4 (3.4)	23.5 (1.6)	21.3 (3.4)	23.2 (3.6)	24.8 (3.4)
2001-2002	28.4 (2.2)	21.4 (4.4)	29.3 (3.7)	30.2 (3.1)	26.9 (2.2)	18.9 (3.0)	31.1 (4.4)	27.3 (2.3)
2003-2004	35.4 (2.7)	26.6 (4.0)	35.6 (5.2)	38.7 (3.6)	31.5 (2.6)	23.5 (3.8)	38.2 (4.0)	30.4 (3.9)
Overweight§								
1999-2000	10.8 (1.5)	6.9 (2.5)‖	11.9 (2.0)	11.8 (1.7)	11.1 (1.8)	10.5 (3.6)‖	11.6 (2.9)	11.0 (1.8)
2001-2002	15.0 (1.5)	9.6 (3.0)‖	15.5 (2.2)	16.6 (2.0)	12.7 (1.9)	7.9 (2.1)	14.1 (3.5)	13.7 (2.8)
2003-2004	17.8 (2.2)	13.0 (3.3)	18.5 (3.9)	19.1 (2.7)	14.8 (1.9)	10.0 (3.1)‖	16.9 (1.9)	15.4 (2.9)
Non-Hispanic black								
At risk of overweight or overweight‡								
1999-2000	31.0 (1.9)	15.2 (3.4)	35.0 (3.6)	35.6 (2.5)	37.9 (2.1)	27.9 (4.8)	36.7 (3.4)	43.7 (2.9)
2001-2002	27.0 (1.4)	26.6 (3.8)	25.3 (2.6)	28.7 (3.2)	36.8 (1.7)	24.0 (3.9)	38.9 (4.4)	40.6 (2.0)
2003-2004	30.4 (2.7)	21.0 (3.8)	34.5 (5.3)	31.4 (3.0)	40.0 (1.9)	27.0 (3.3)	45.6 (4.0)	42.1 (2.3)
Overweight§								
1999-2000	16.3 (1.2)	NA	17.1 (2.5)	21.0 (2.5)	21.4 (1.4)	11.7 (2.6)	22.4 (2.3)	25.2 (2.7)
2001-2002	15.5 (1.3)	9.7 (2.2)	16.9 (1.8)	16.7 (2.5)	19.7 (1.4)	7.5 (2.3)‖	23.1 (4.2)	22.0 (2.4)
2003-2004	16.4 (1.5)	9.7 (2.7)	17.5 (3.0)	18.5 (1.6)	23.8 (1.4)	16.3 (3.7)	26.5 (2.8)	25.4 (2.0)
Mexican American								
At risk of overweight or overweight‡								
1999-2000	39.0 (2.1)	26.8 (3.4)	42.3 (4.3)	43.6 (2.5)	34.2 (2.2)	19.3 (3.9)	35.0 (4.0)	42.9 (4.5)
2001-2002	39.9 (2.0)	28.3 (5.4)	46.0 (3.7)	40.2 (2.9)	33.9 (2.2)	31.8 (6.6)	32.2 (3.3)	36.7 (2.8)
2003-2004	41.4 (1.9)	38.3 (5.9)	47.9 (3.1)	37.3 (2.2)	32.2 (2.5)	26.7 (4.1)	37.4 (5.0)	31.1 (2.8)
Overweight§								
1999-2000	23.5 (1.5)	13.1 (2.3)	26.7 (2.9)	27.2 (3.1)	16.8 (1.9)	8.7 (3.4)‖	19.8 (2.4)	19.3 (2.7)
2001-2002	22.0 (1.3)	15.4 (3.6)	26.0 (2.9)	21.8 (2.4)	17.0 (1.9)	16.3 (5.9)‖	13.6 (3.2)	20.3 (2.8)
2003-2004	22.0 (1.6)	23.2 (5.1)	25.3 (2.2)	18.3 (1.7)	16.2 (2.3)	15.1 (5.0)‖	19.4 (3.9)	14.1 (2.0)

Abbreviation: NA, data not available.
*Body mass index (BMI; calculated as weight in kilograms divided by the square of height in meters) was rounded to the nearest tenth. Pregnant females were excluded.
†Includes racial/ethnic groups not shown separately.
‡BMI for age at 85th percentile or higher.
§BMI for age at 95th percentile or higher.
‖Does not meet standard of statistical reliability and precision. Relative SE was greater than 30% but less than 40%.

Source: Ogden, C. L., Carroll, M.D., Curtin, L.R., McDowell M.A., Tabak, C.J., Flegal K.M. (2006). Prevalence of Overweight and Obesity in the United States, 1999-2004. Journal American Medical Association (JAMA), 295, 1549-1555

X. Appendix C – Overweight children & adolescents 1963–65 through 1999–2002

Age, sex, race, and Hispanic origin[1]	1963–65 1966–70[2]	1971–74	1976–80[3]	1988–94	1999–2002
6–11 years of age			Percent of population (standard error)		
Both sexes[4]	4.2	4.0	6.5	11.3 (1.0)	15.8 (1.1)
Boys	4.0	4.3	6.6	11.6 (1.3)	16.9 (1.3)
Not Hispanic or Latino:					
White only	- - -	- - -	6.1	10.7 (2.0)	14.0 (1.5)
Black or African American only	- - -	- - -	6.8	12.3 (1.4)	17.0 (1.5)
Mexican	- - -	- - -	13.3	17.5 (2.4)	26.5 (2.2)
Girls[5]	4.5	3.6	6.4	11.0 (1.4)	14.7 (1.6)
Not Hispanic or Latino:					
White only	- - -	- - -	5.2	*9.8 (2.0)	13.1 (2.3)
Black or African American only	- - -	- - -	11.2	17.0 (1.6)	22.8 (2.5)
Mexican	- - -	- - -	9.8	15.3 (2.5)	17.1 (2.0)
12–19 years of age					
Both sexes[4]	4.6	6.1	5.0	10.5 (0.9)	16.1 (0.8)
Boys	4.5	6.1	4.8	11.3 (1.3)	16.7 (0.9)
Not Hispanic or Latino:					
White only	- - -	- - -	3.8	11.6 (1.9)	14.6 (1.3)
Black or African American only	- - -	- - -	6.1	10.7 (1.4)	18.7 (1.7)
Mexican	- - -	- - -	7.7	14.1 (1.8)	24.7 (1.9)
Girls[5]	4.7	6.2	5.3	9.7 (1.1)	15.4 (1.2)
Not Hispanic or Latino:					
White only	- - -	- - -	4.6	8.9 (1.7)	12.7 (1.8)
Black or African American only	- - -	- - -	10.7	16.3 (2.1)	23.6 (1.8)
Mexican	- - -	- - -	8.8	*13.4 (3.1)	19.6 (1.9)

Source: National Center for Health Statistics. Health, United States, 2004 with Chartbook on Trends in the Health of Americans. Hyattsville, Maryland: 2004.

XI. Appendix D – Computer Simulation Theoretical Example

To explore the concept of simulation consider a theoretical example where an individual suffers from frequent headaches. Suppose headaches are classified into categories of weak, medium, bad or pounding. Table D.1 lists all possible headache outcomes. The corresponding probabilities indicate the likelihood of the individual's status escalating to a given severity level within a 24 hour period.

Table D.1 Simulation example - sample probabilities

Severity Level	Outcomes	Probability
1	no headache	0.70
2	weak headache	0.12
3	medium headache	0.09
4	bad headache	0.06
5	pounding headache	0.03

The above probabilities are helpful. However, headache outcome probabilities are more useful when defined using conditional probabilities. For example, assume that headache severity is related to the quality of lunch consumed that day (e.g., an individual has a higher probability of getting a headache given the individual ate a low quality lunch).

The first step is to develop a distribution of the conditional variable. The following table provides definitions for quality of lunch consumed in a 24-hour period.

Table D.2 Simulation example - initial lunch quality levels

Quality Level	Category	Probability
1	skipped lunch	0.05
2	poor lunch	0.20
3	fair lunch	0.35
4	good lunch	0.30
5	great lunch	0.10

Utilizing Bayes Law, five new probability distributions are identified within the next five tables.

Table D.3 Probabilities by headache severity given individual skipped lunch

Severity Level	Outcomes	Probability
1	no headache	0.62
2	weak headache	0.14
3	medium headache	0.11
4	bad headache	0.08
5	pounding headache	0.05

Table D.4 Probabilities by headache severity given individual ate a poor quality lunch

Severity Level	Outcomes	Probability
1	no headache	0.66
2	weak headache	0.13
3	medium headache	0.10
4	bad headache	0.07
5	pounding headache	0.04

Table D.5 Probabilities by headache severity given individual ate a fair quality lunch

Severity Level	Outcomes	Probability
1	no headache	0.70
2	weak headache	0.12
3	medium headache	0.09
4	bad headache	0.06
5	pounding headache	0.03

Table D.6 Probabilities by headache severity given individual ate a good quality lunch

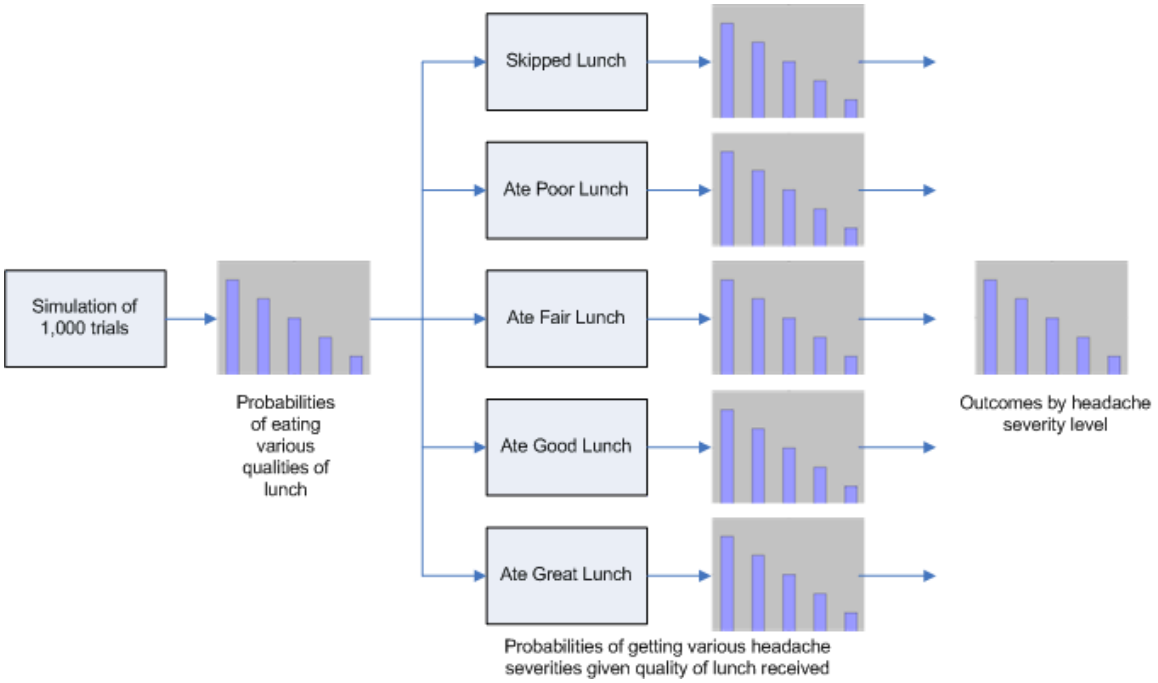
Severity Level	Outcomes	Probability
1	no headache	0.74
2	weak headache	0.11
3	medium headache	0.08
4	bad headache	0.05
5	pounding headache	0.02

Table D.7 Probabilities by headache severity given individual ate a lunch of great quality

Severity Level	Outcomes	Probability
1	no headache	0.78
2	weak headache	0.10
3	medium headache	0.07
4	bad headache	0.04
5	pounding headache	0.01

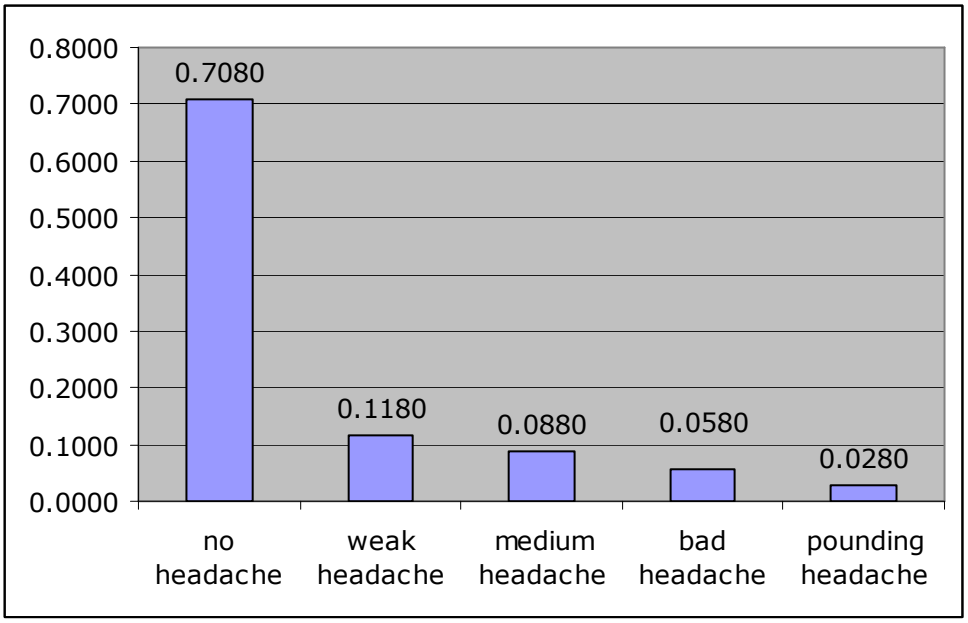
Utilizing the above probabilities a model is constructed as shown below.

Figure D.1 Simulation model of headache severity



Utilizing a random number generator, a simulation of 1,000 Monte Carlo trials is performed. The resulting probabilities by headache severity are defined below.

Figure D.2 Relative frequency diagram of headache severity



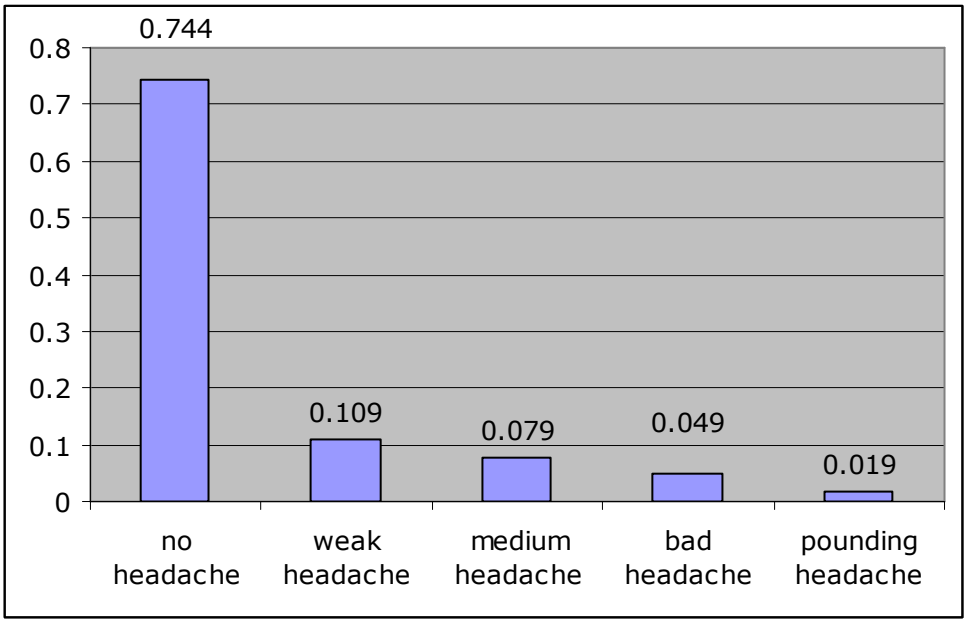
Now that the current situation is modeled, assume an intervention is implemented that improves the probability distribution for quality of lunch consumed. The question is now: What is the expected outcome by headache severity given recent changes in quality of lunch consumed? For this case, a revised probability distribution for quality of lunch consumed is utilized as follows:

Table D.8 Simulation example - revised lunch quality levels

Quality Level	Category	Probability
1	skipped lunch	0.00
2	poor lunch	0.05
3	fair lunch	0.20
4	good lunch	0.35
5	great lunch	0.40

The only modification required in the existing model is a change for probabilities of lunch quality. The simulation is run again utilizing 1,000 Monte Carlo trails. The results are displayed in the following relative frequency diagram.

Figure D.3 Relative frequency diagram for headache severity after intervention



The new distribution of headache severity has significantly shifted to the left, indicating a drop in headache severity level. This may provide useful when comparing the outcomes of various interventions.

XII. Appendix E – Relationships between quetelet index and risk factor probability

Figure XII-1 Relationship of quetelet index in children ages 5-10 to probability of total cholesterol > 200 mg/dL

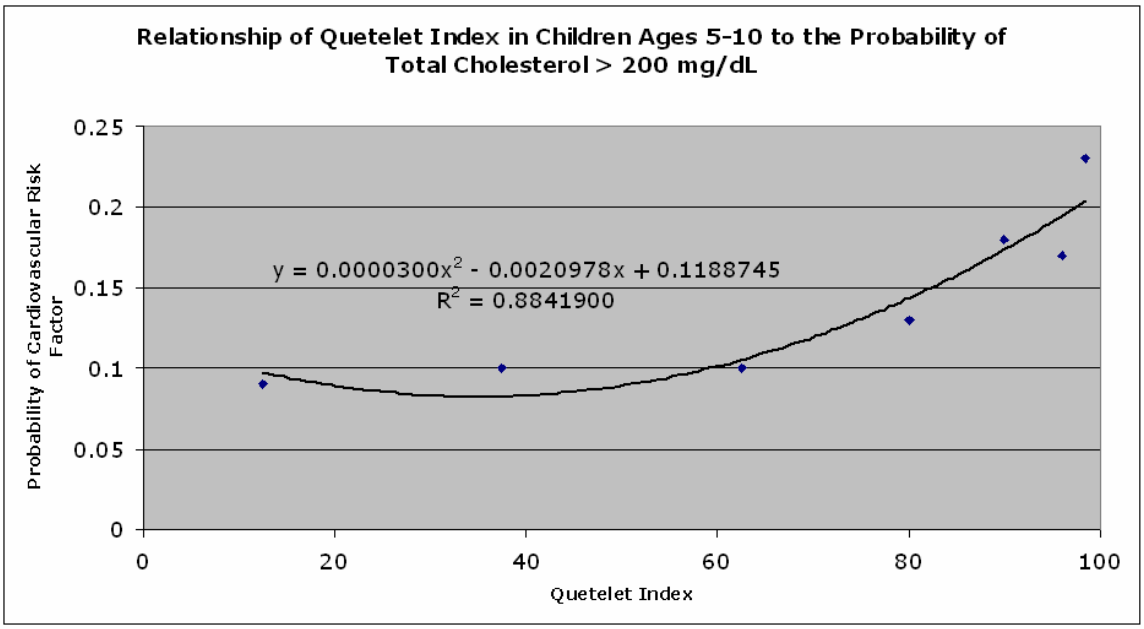


Figure XII-2 Relationship of quetelet index in children ages 11-17 to probability of total cholesterol > 200 mg/dL

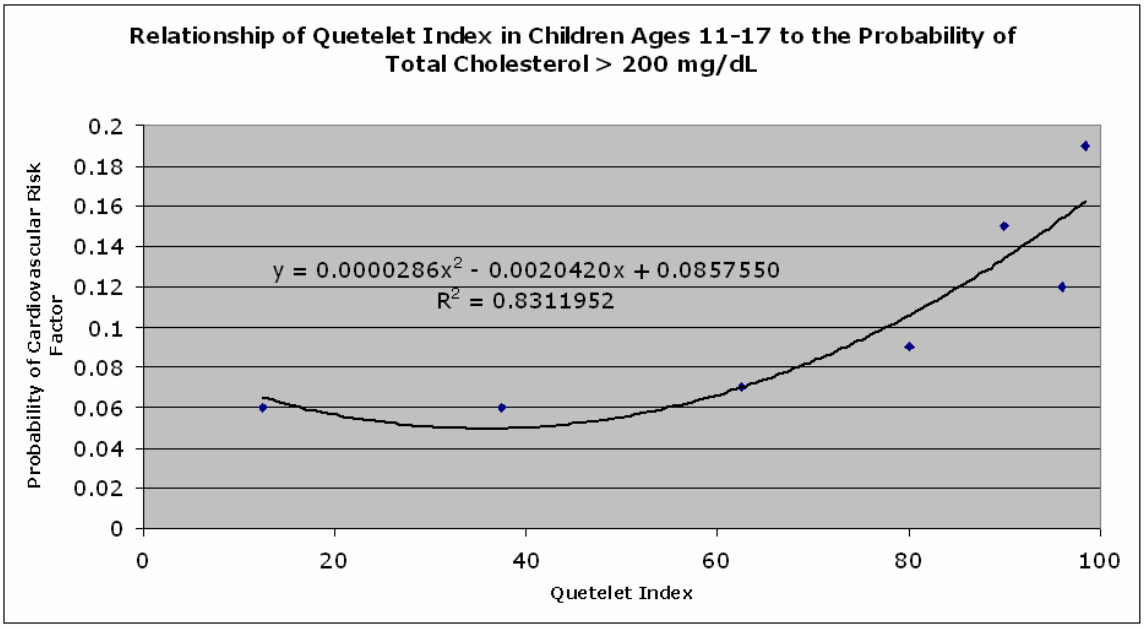


Figure XII-3 Relationship of quetelet index in children ages 5-10 to probability of triglycerides > 130 mg/dL

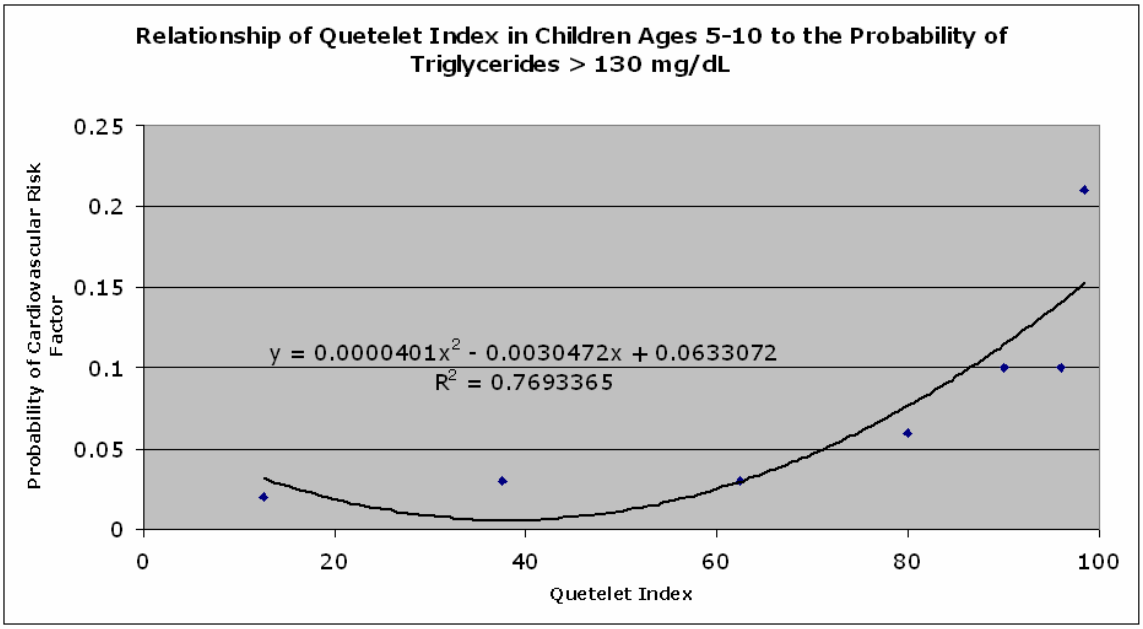


Figure XII-4 Relationship of quetelet index in children ages 11-17 to probability of triglycerides > 130 mg/dL

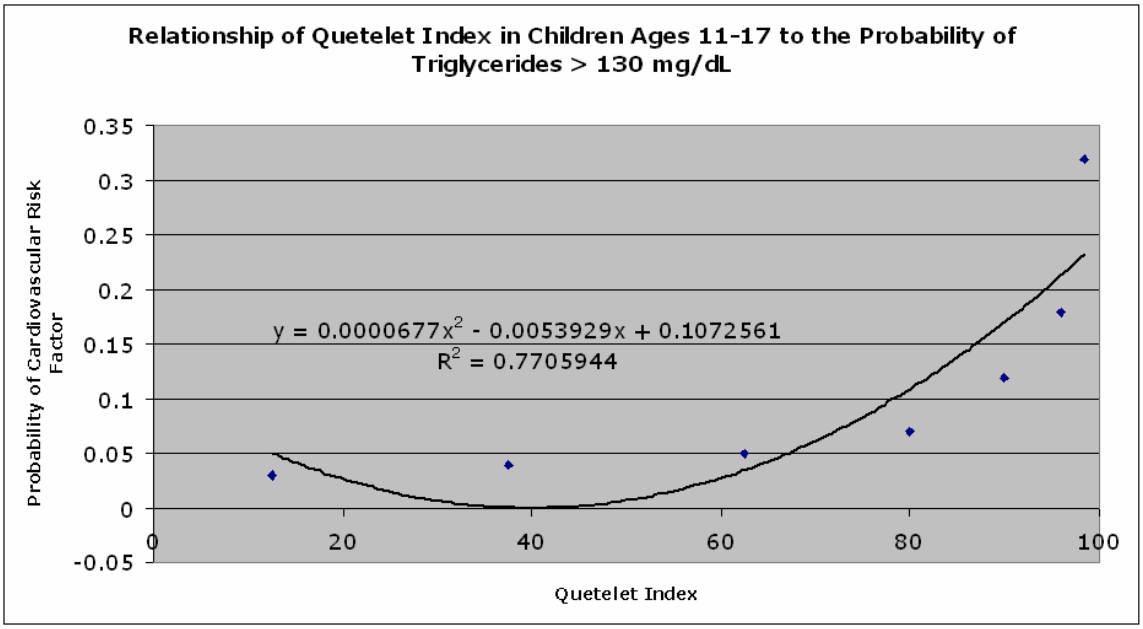


Figure XII-5 Relationship of quetelet index in children ages 5-10 to probability of low-density lipoprotein cholesterol > 130 mg/dL

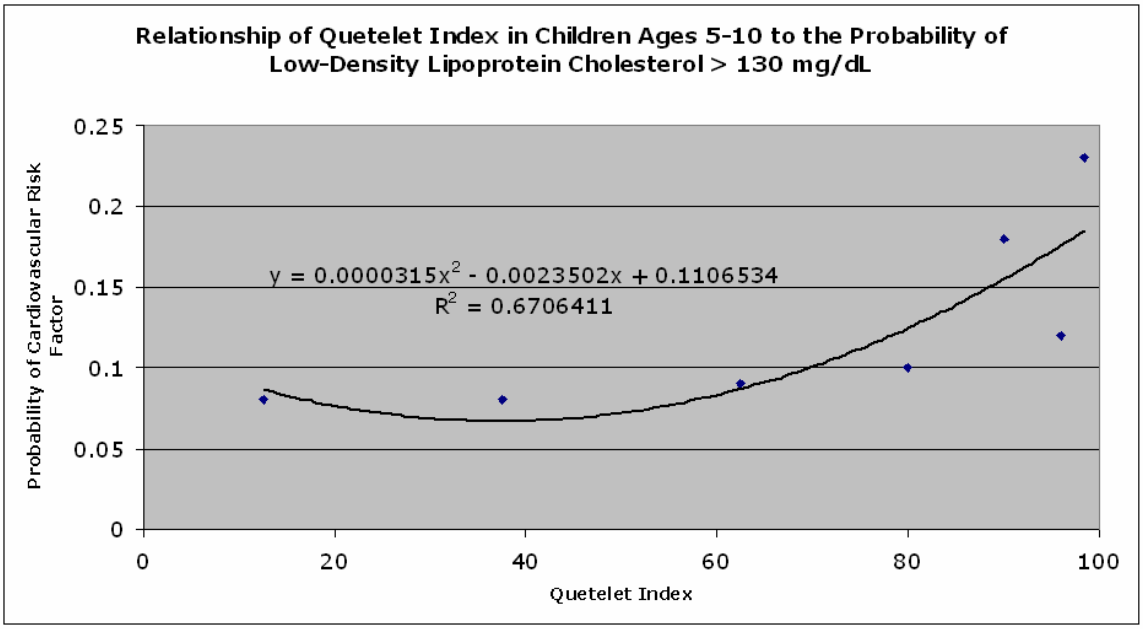


Figure XII-6 Relationship of quetelet index in children ages 11-17 to probability of low-density lipoprotein cholesterol > 130 mg/dL

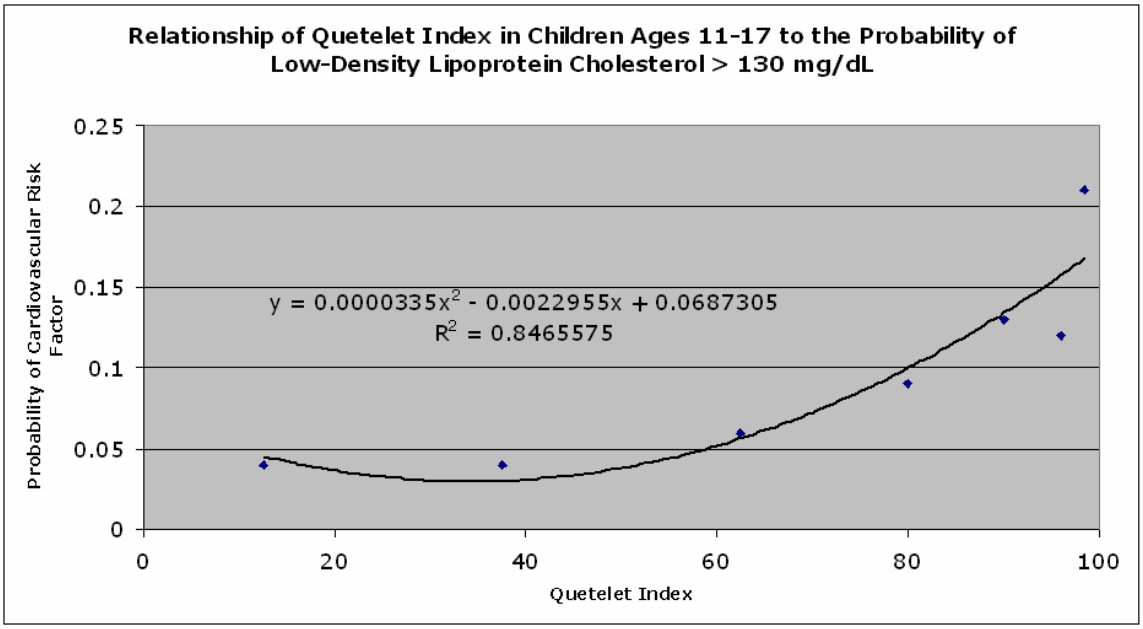


Figure XII-7 Relationship of quetelet index in children ages 5-10 to probability of high-density lipoprotein cholesterol < 35 mg/dL

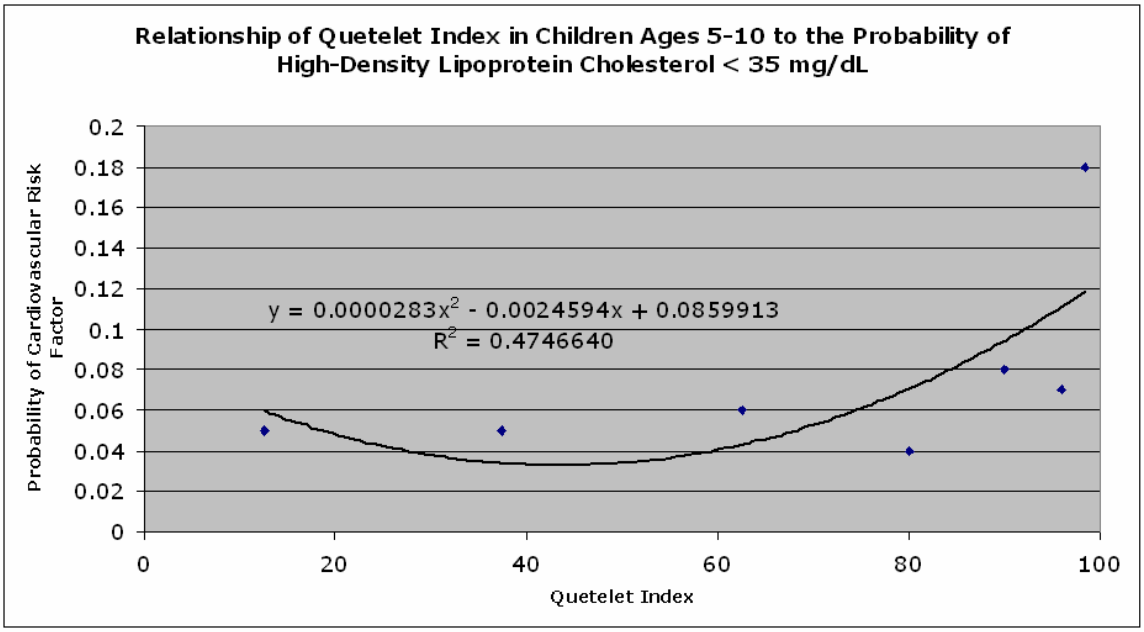


Figure XII-8 Relationship of quetelet index in children ages 11-17 to probability of high-density lipoprotein cholesterol < 35 mg/dL

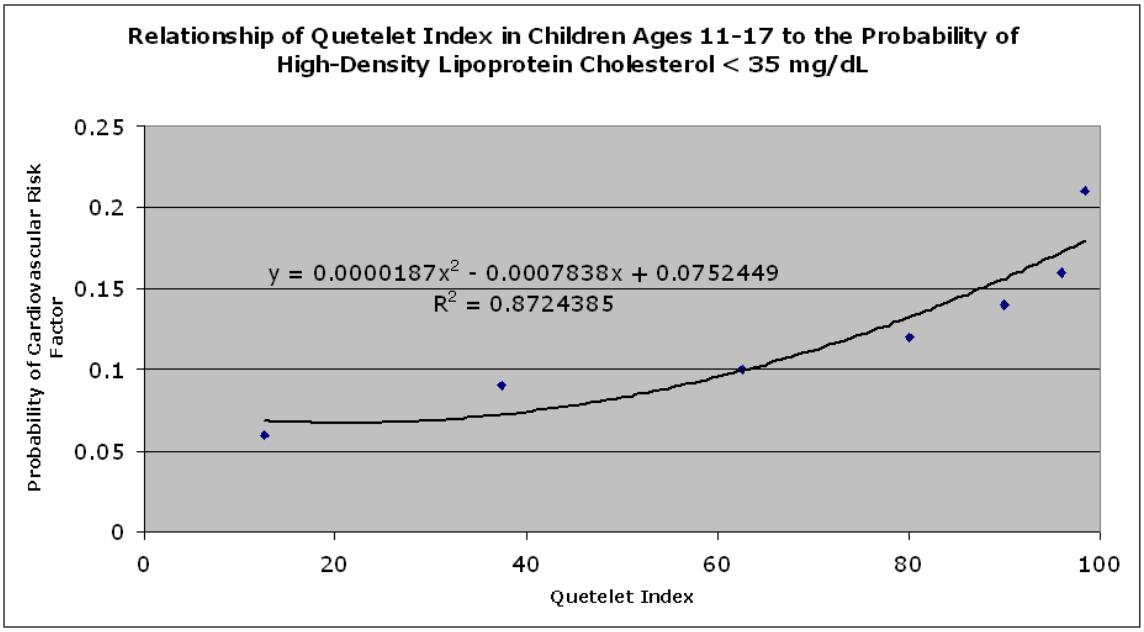


Figure XII-9 Relationship of quetelet index in children ages 5-10 to probability of fasting insulin > 95th percentile

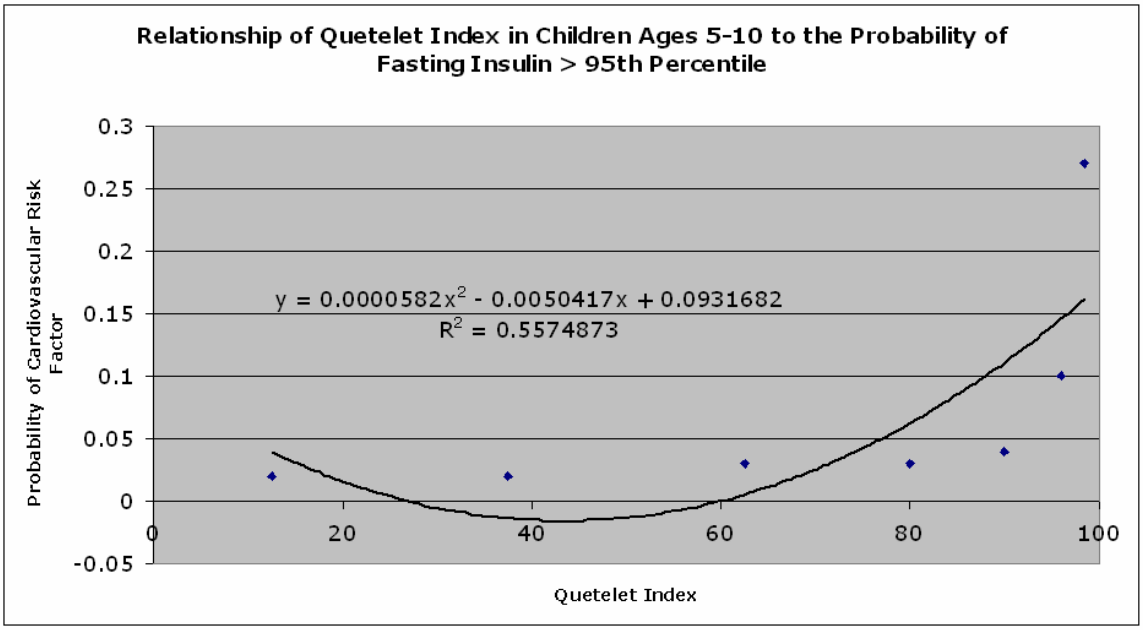


Figure XII-10 Relationship of quetelet index in children ages 11-17 to probability of fasting insulin > 95th percentile

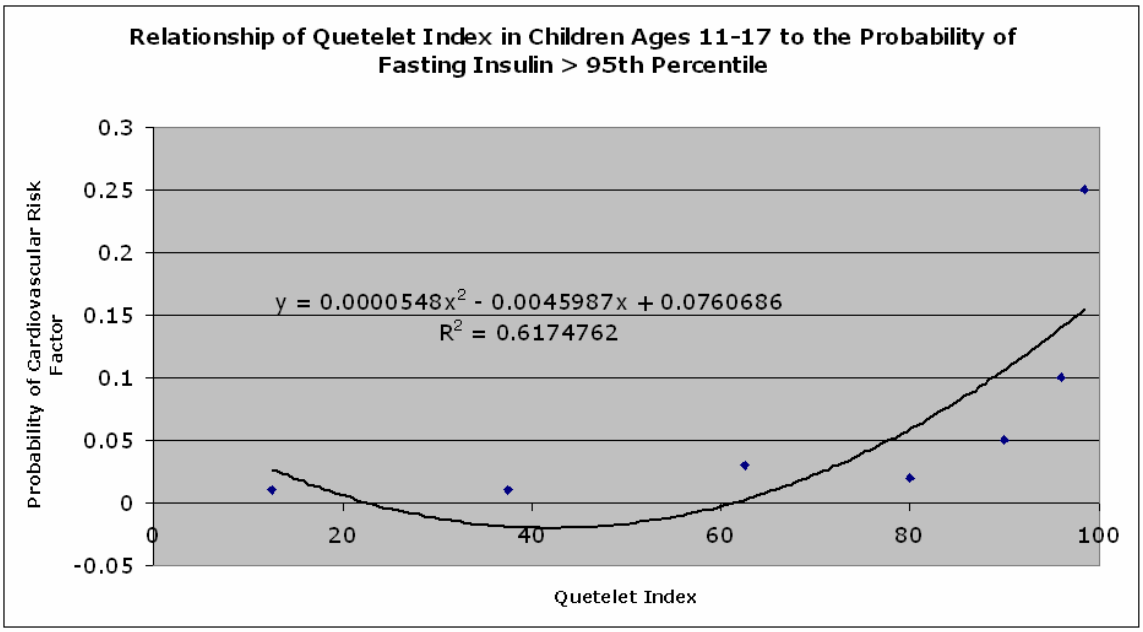


Figure XII-11 Relationship of quetelet index in children Ages 5-10 to probability of systolic blood pressure > 95th percentile

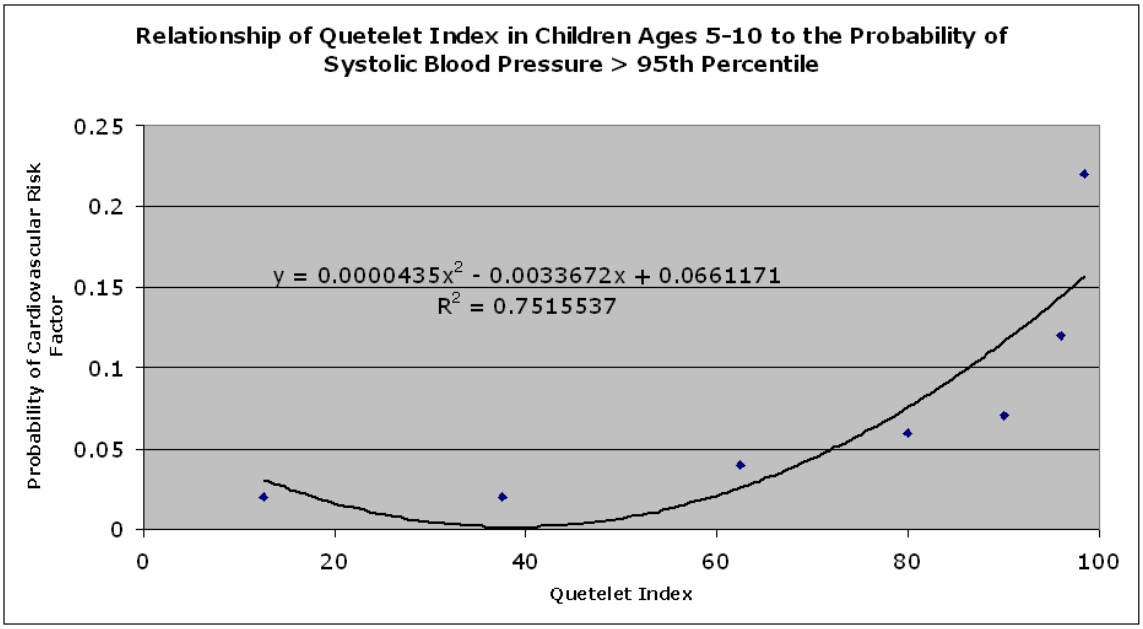


Figure XII-12 Relationship of quetelet index in children ages 11-17 to probability of systolic blood pressure > 95th percentile

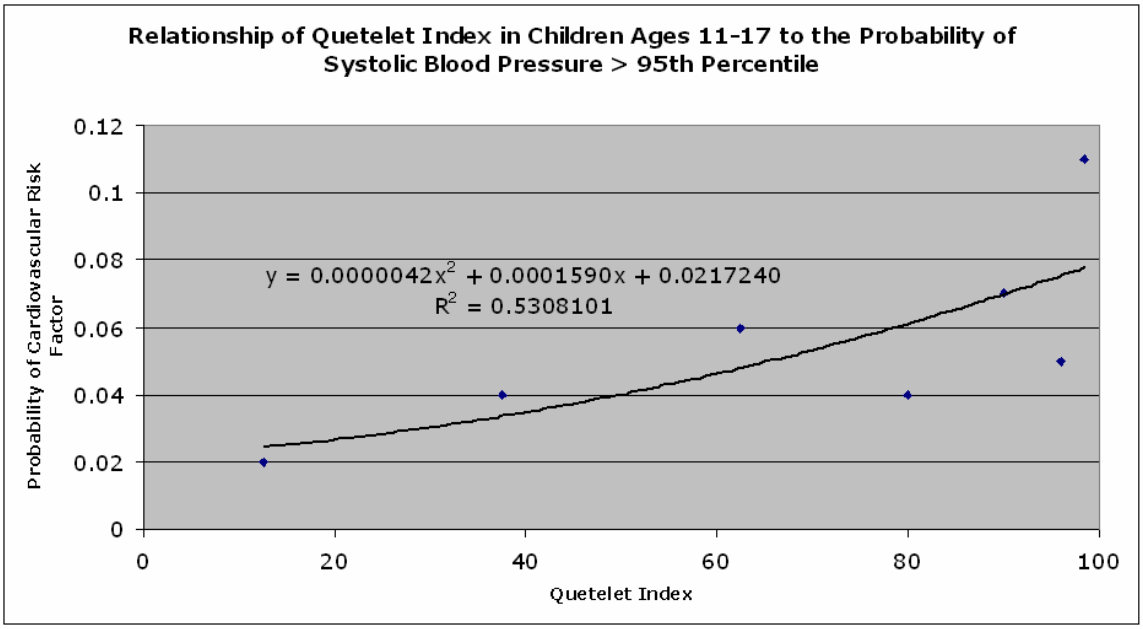


Figure XII-13 Relationship of quetelet index in children ages 5-10 to probability of diastolic blood pressure > 95th percentile

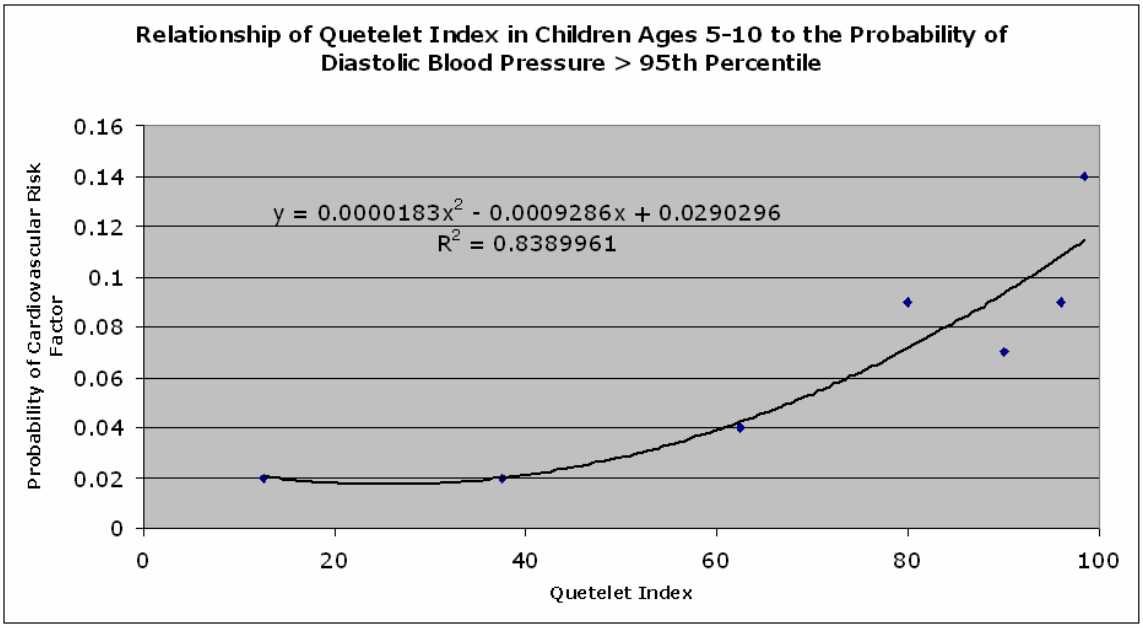
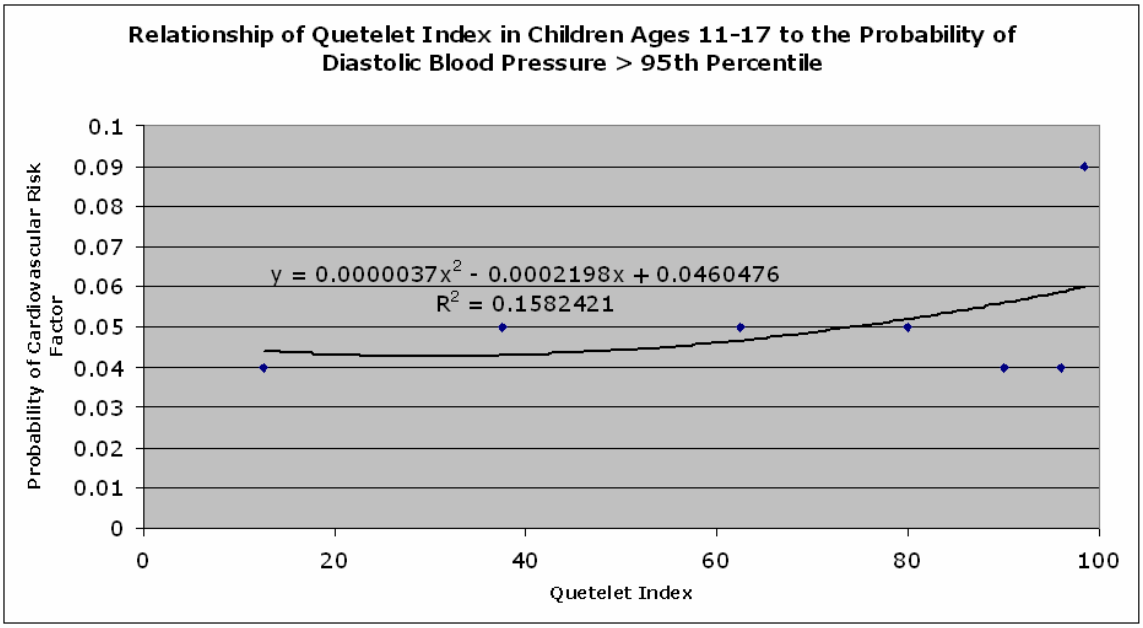


Figure XII-14 Relationship of quetelet index in children ages 11-17 to probability of diastolic blood pressure > 95th percentile



XIII. Appendix F – Model comparison by cardiovascular risk factor

Figure XIII-1 Simulation comparison- Children ages 5 to 10 w/ total cholesterol > 200 mg/dL

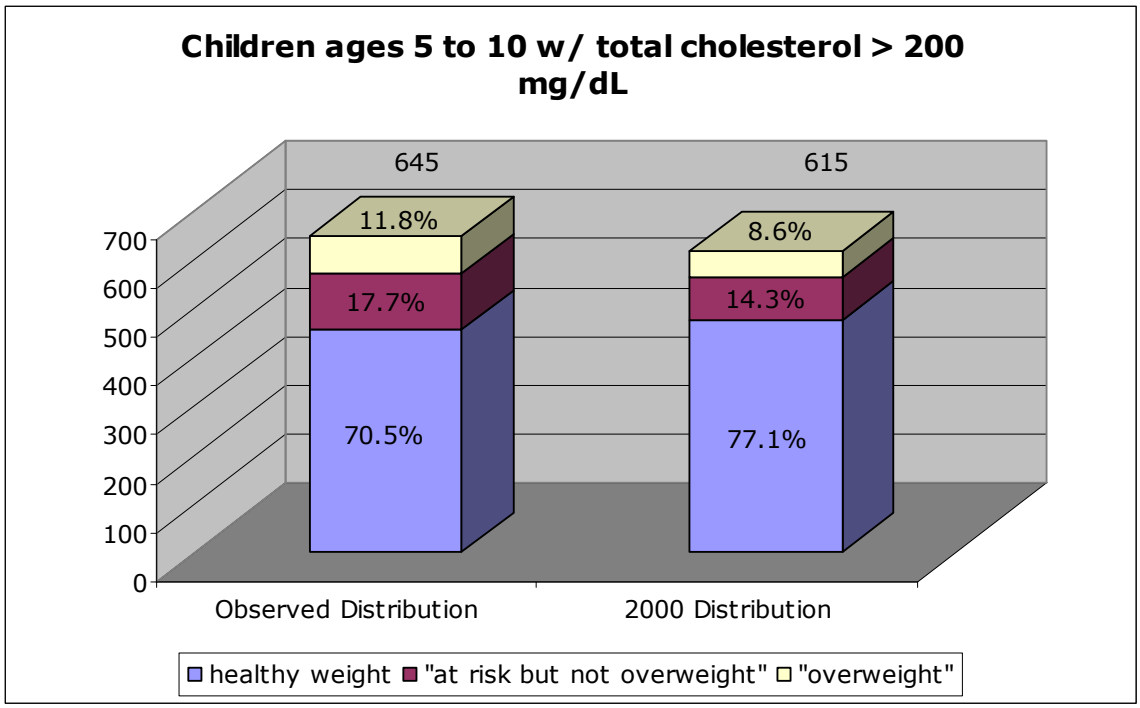


Figure XIII-2 Simulation comparison- Children ages 5 to 10 w/ triglycerides > 130 mg/dL

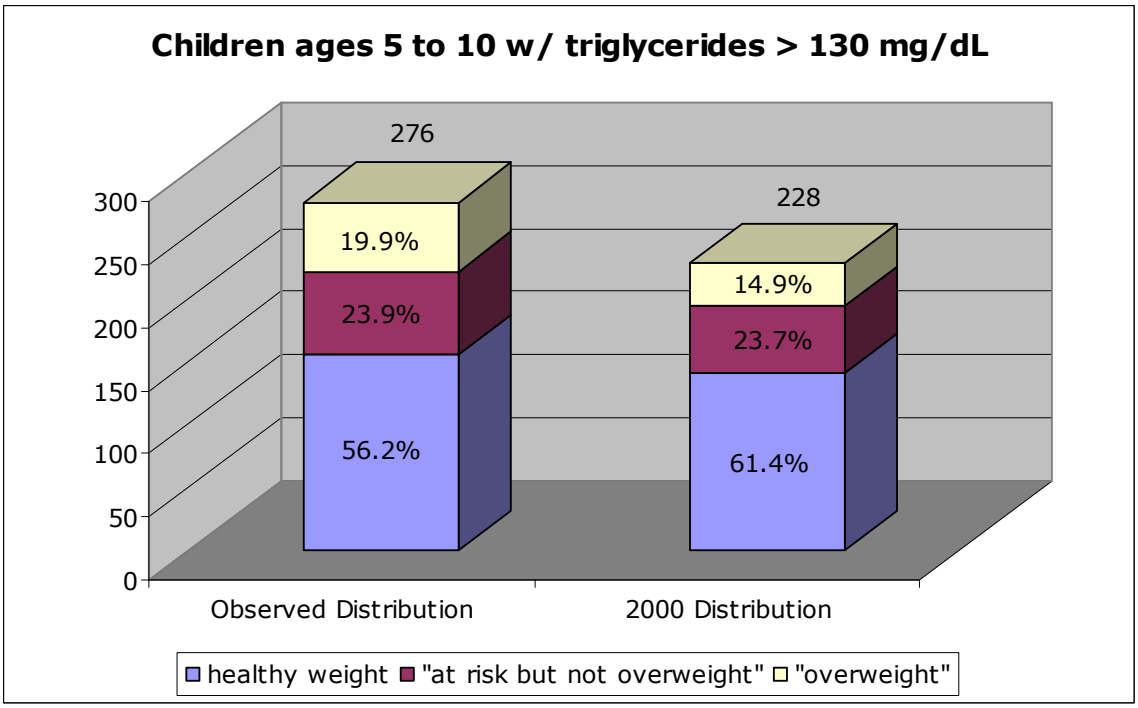


Figure XIII-3 Simulation comparison- Children ages 5 to 10 w/ low-density lipoprotein cholesterol > 130 mg/dL

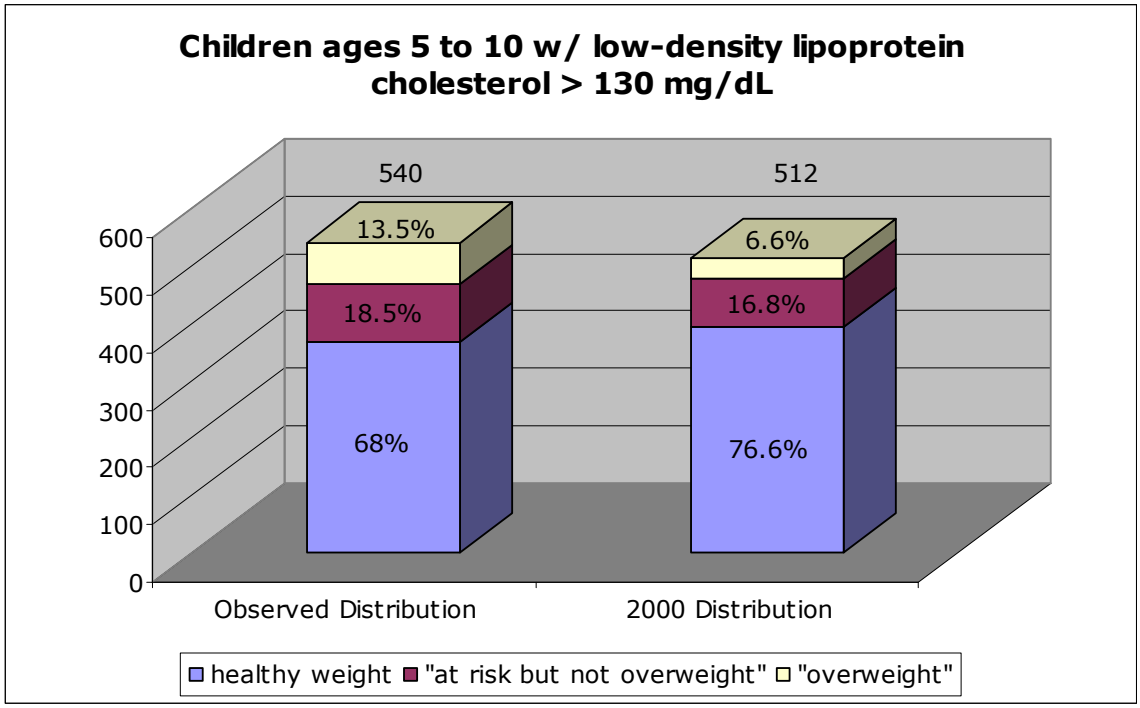


Figure XIII-4 Simulation comparison- Children ages 5 to 10 w/ high-density lipoprotein cholesterol < 35 mg/dL

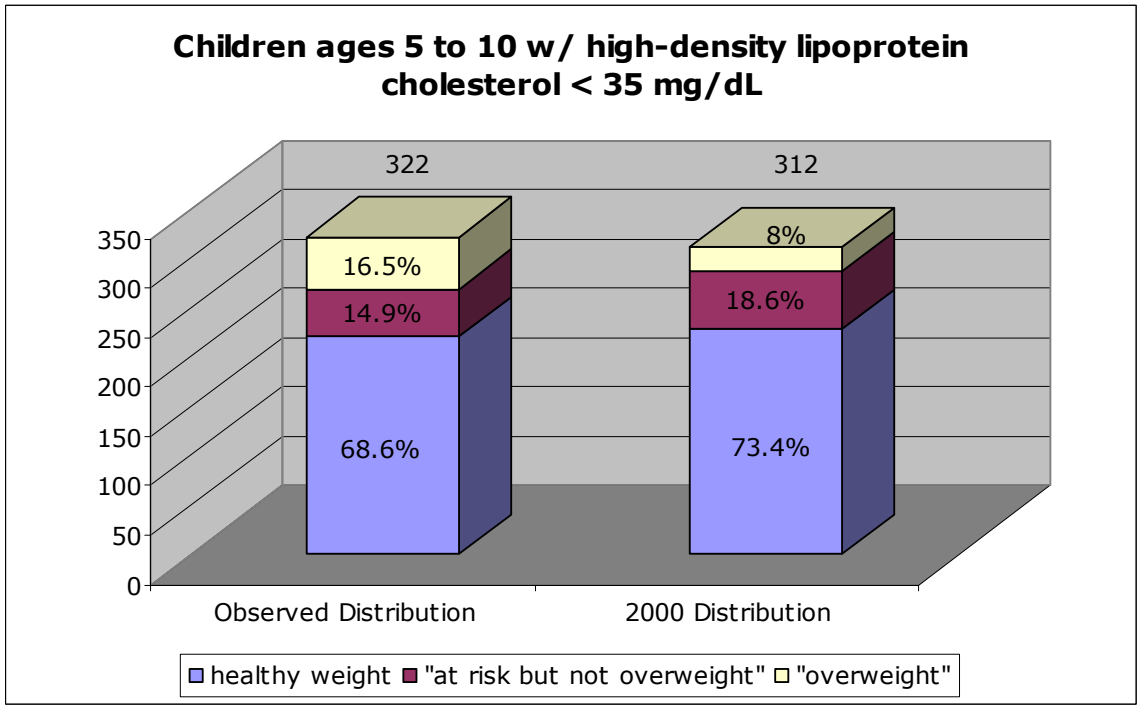


Figure XIII-5 Simulation comparison- Children ages 5 to 10 w/ fasting insulin > 95th percentile

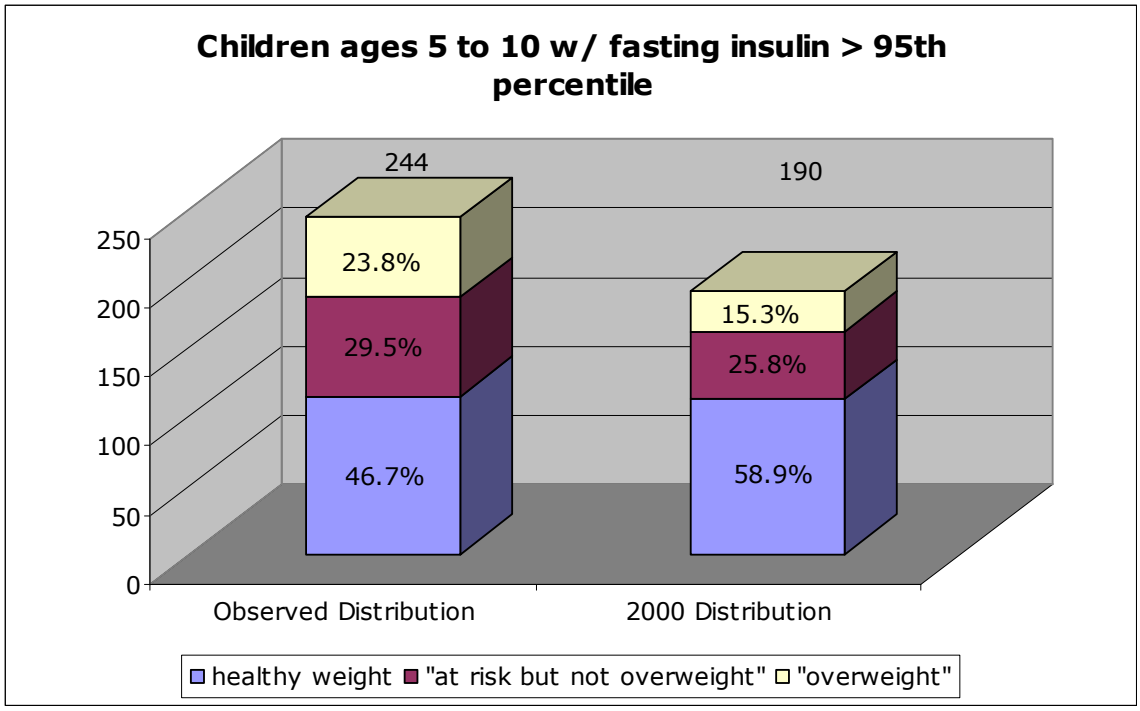


Figure XIII-6 Simulation comparison- Children ages 5 to 10 w/ systolic blood pressure > 95th percentile

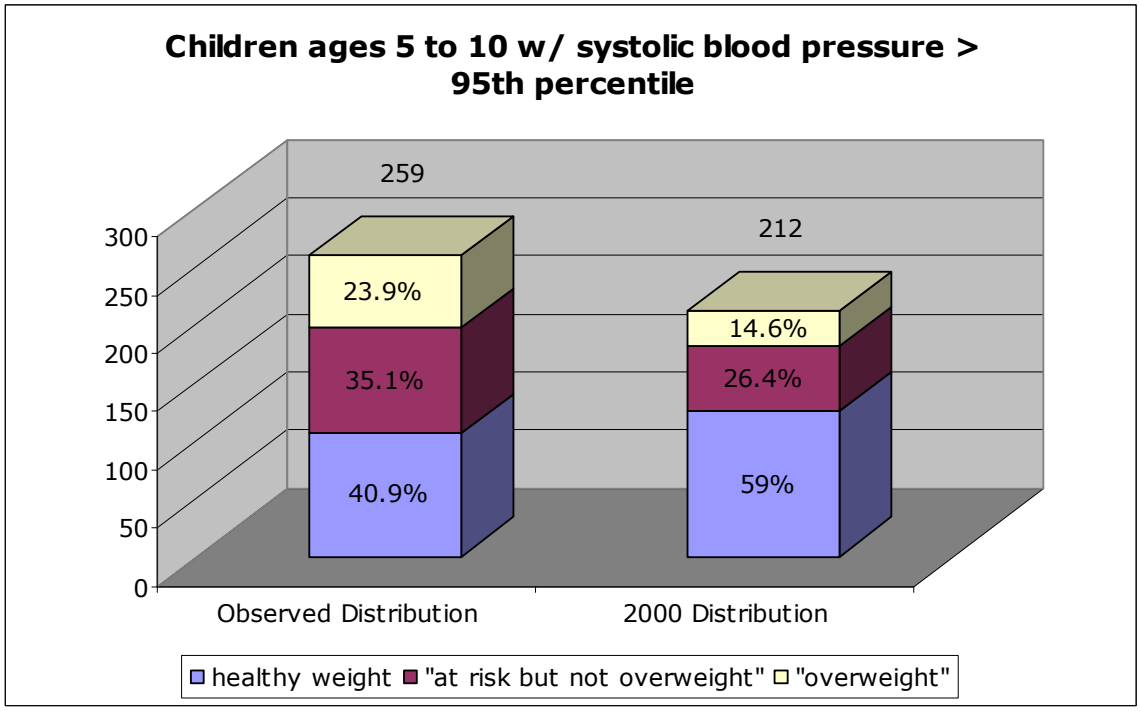


Figure XIII-7 Simulation comparison- Children ages 5 to 10 w/ diastolic blood pressure > 95th percentile

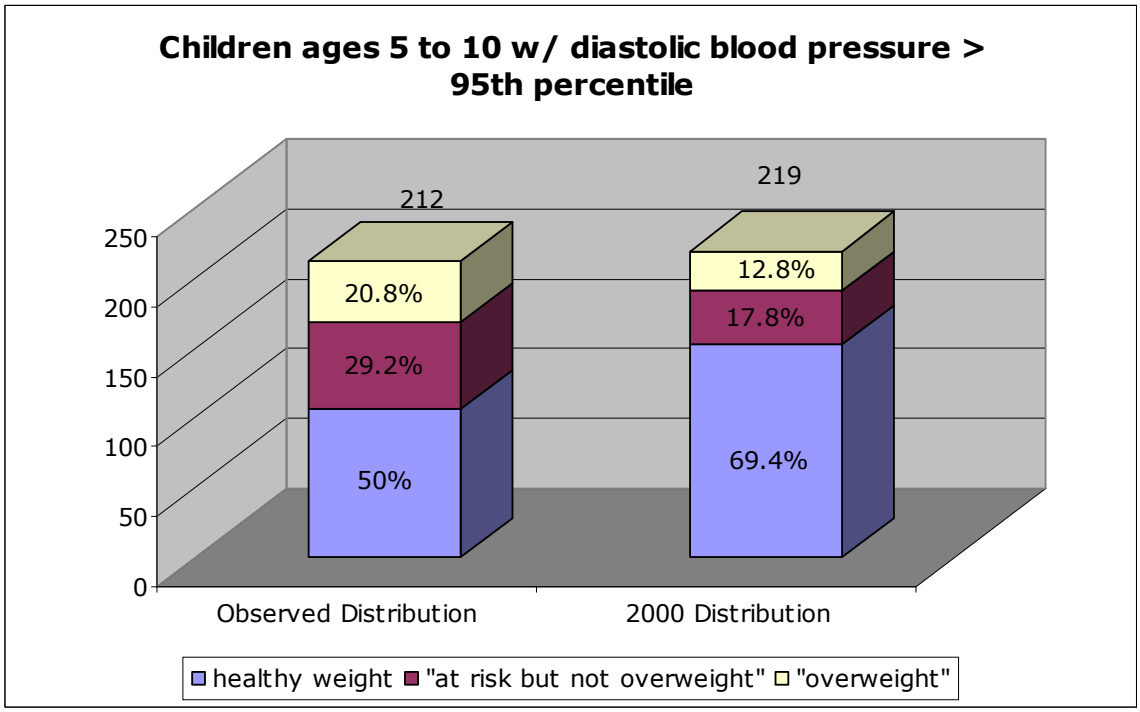


Figure XIII-8 Simulation comparison- Children ages 5 to 10 w/ 0 out of 7 risk factors

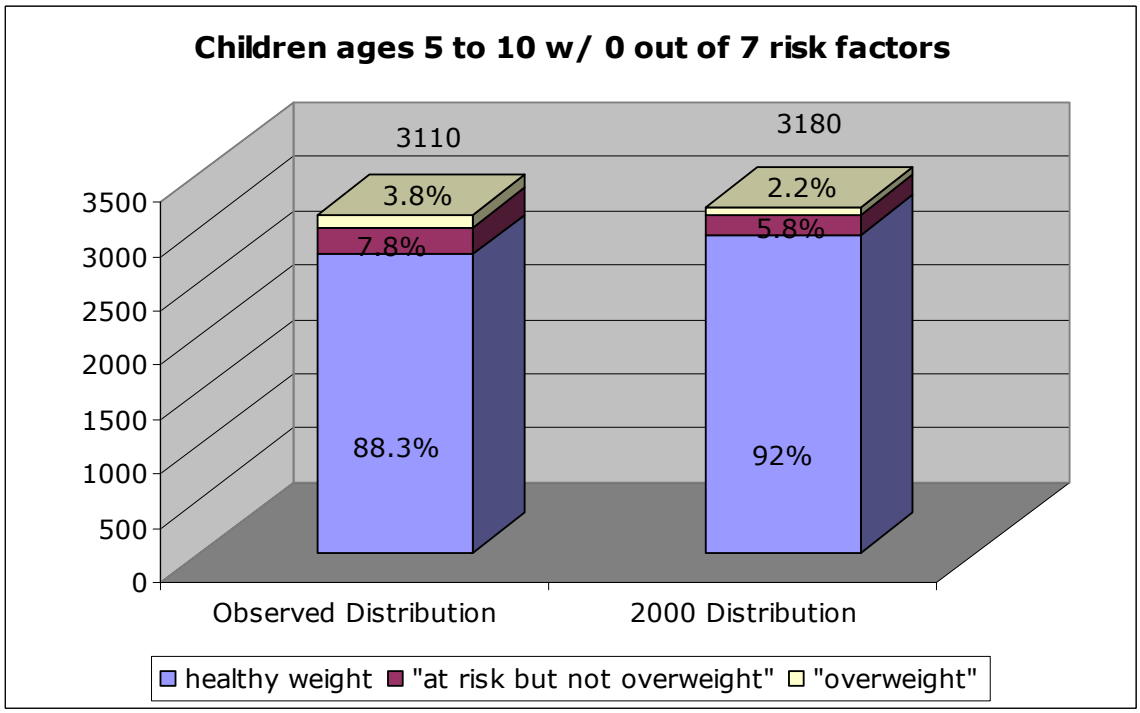


Figure XIII-9 Simulation comparison- Children ages 5 to 10 w/ 1 out of 7 risk factors

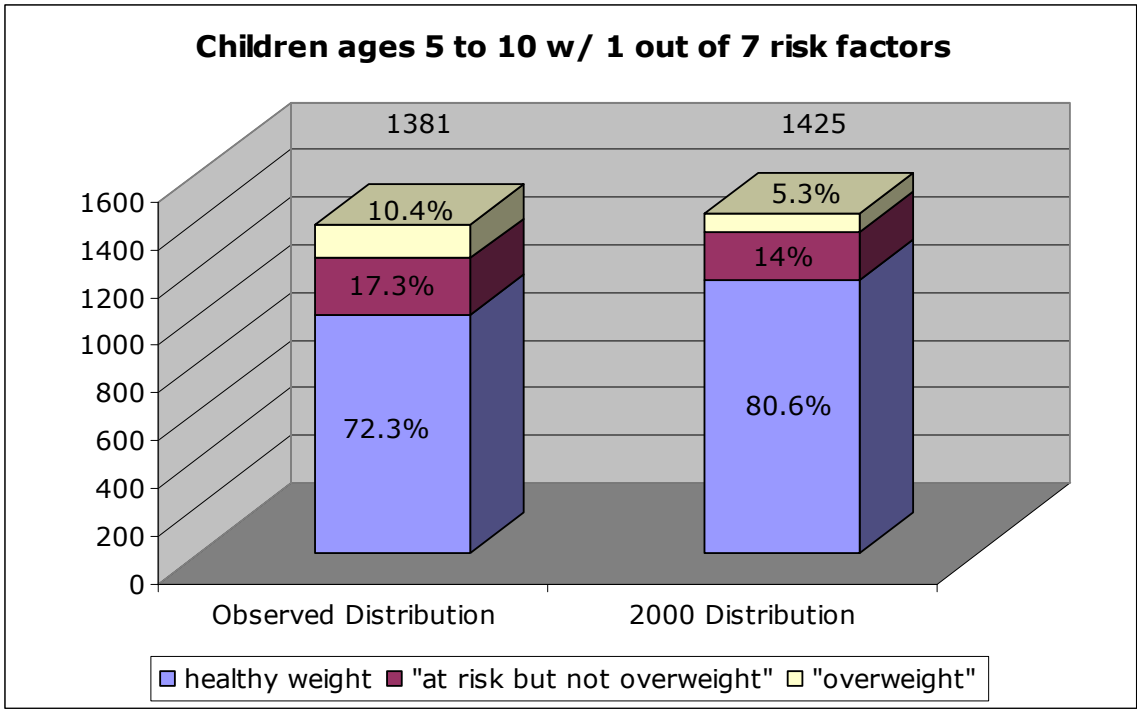


Figure XIII-10 Simulation comparison- Children ages 5 to 10 w/ 2 out of 7 risk factors

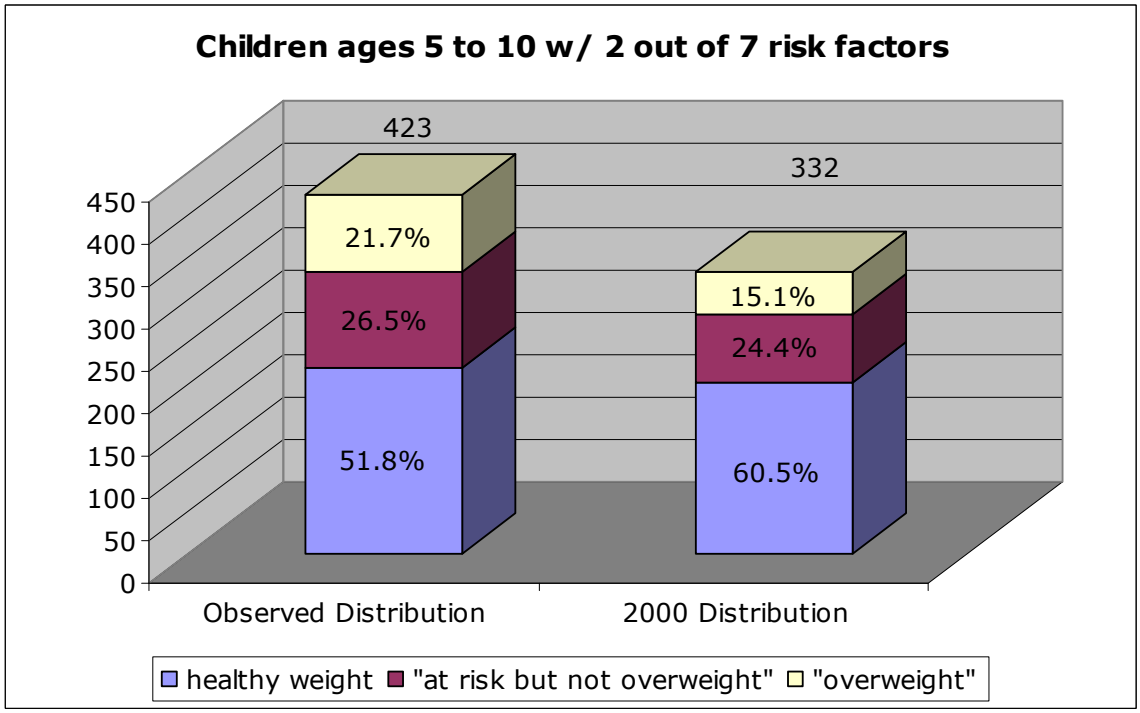


Figure XIII-11 Simulation comparison- Children ages 5 to 10 w/ 3 out of 7 risk factors

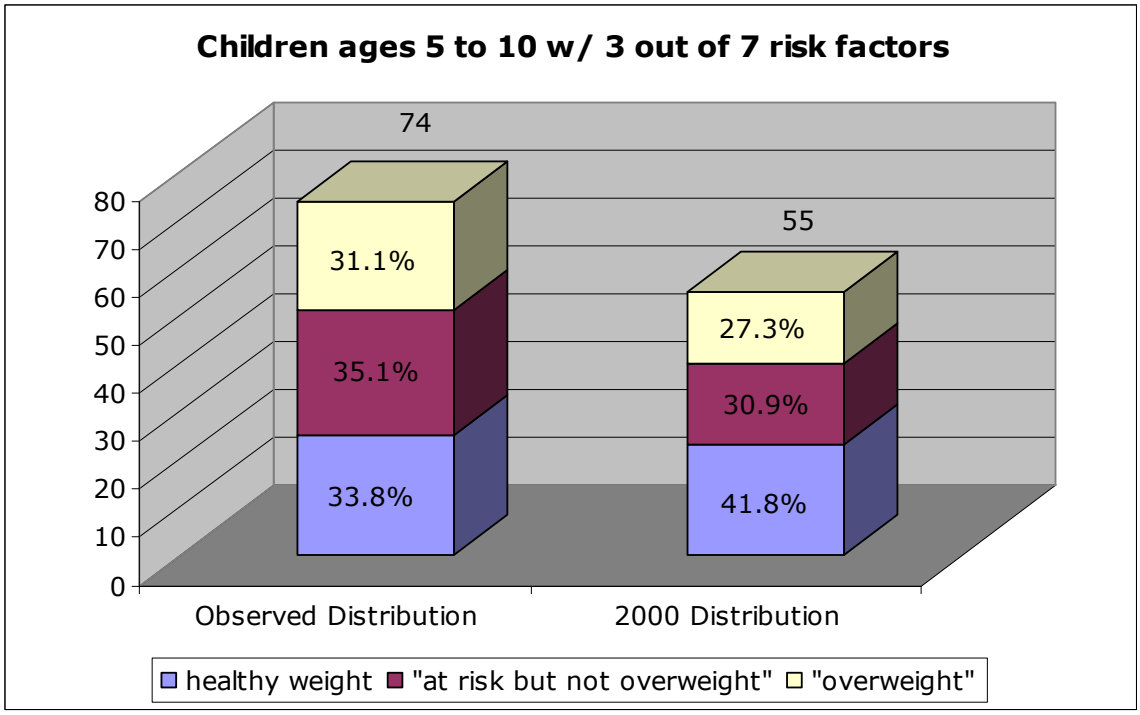


Figure XIII-12 Simulation comparison- Children ages 5 to 10 w/ 4 out of 7 risk factors

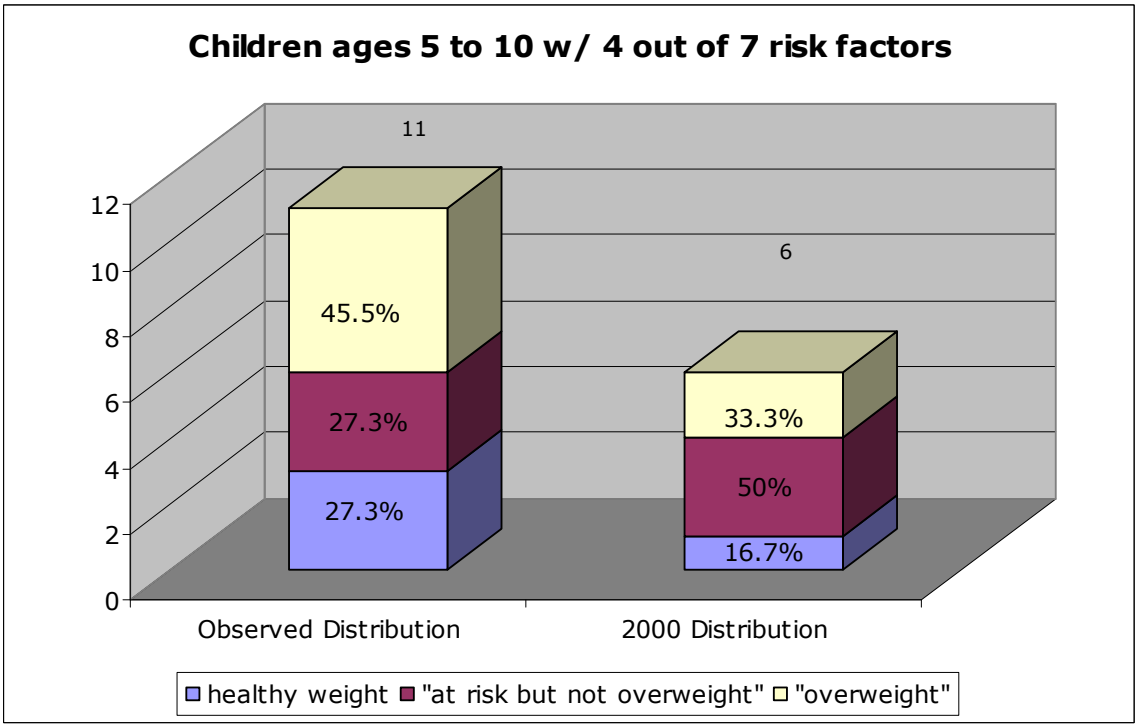


Figure XIII-13 Simulation comparison- Children ages 5 to 10 w/ (5 or more) out of 7 risk factors

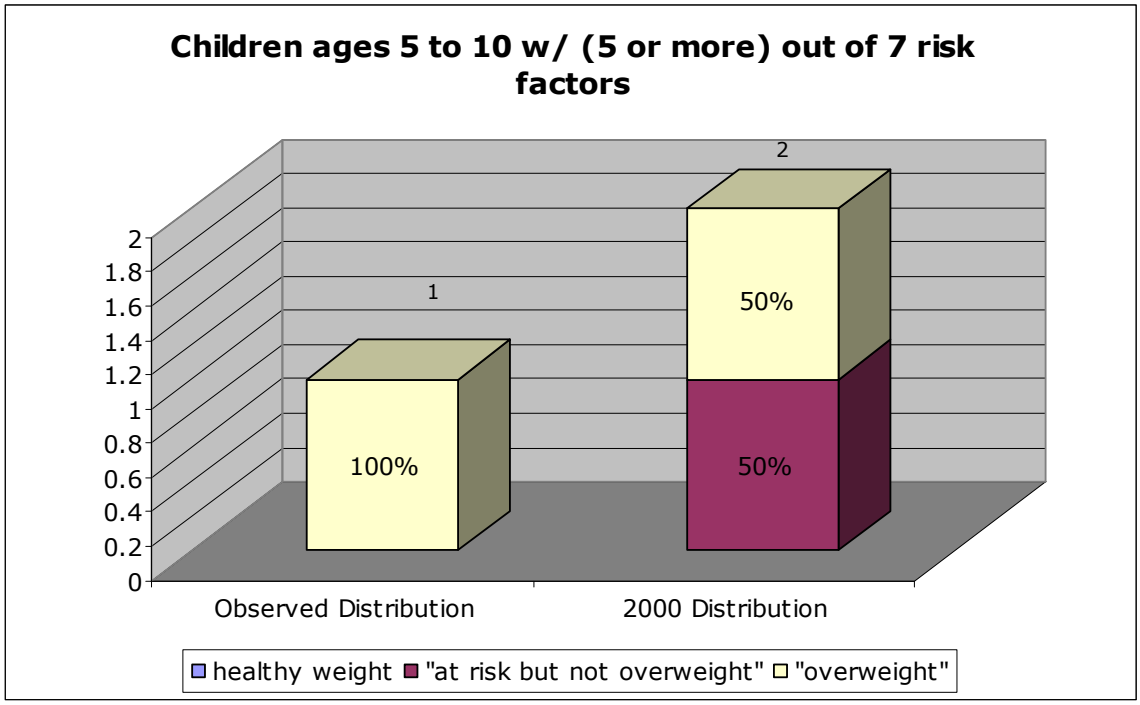


Figure XIII-14 Simulation comparison- Children ages 11 to 17 w/ total cholesterol > 200 mg/dL

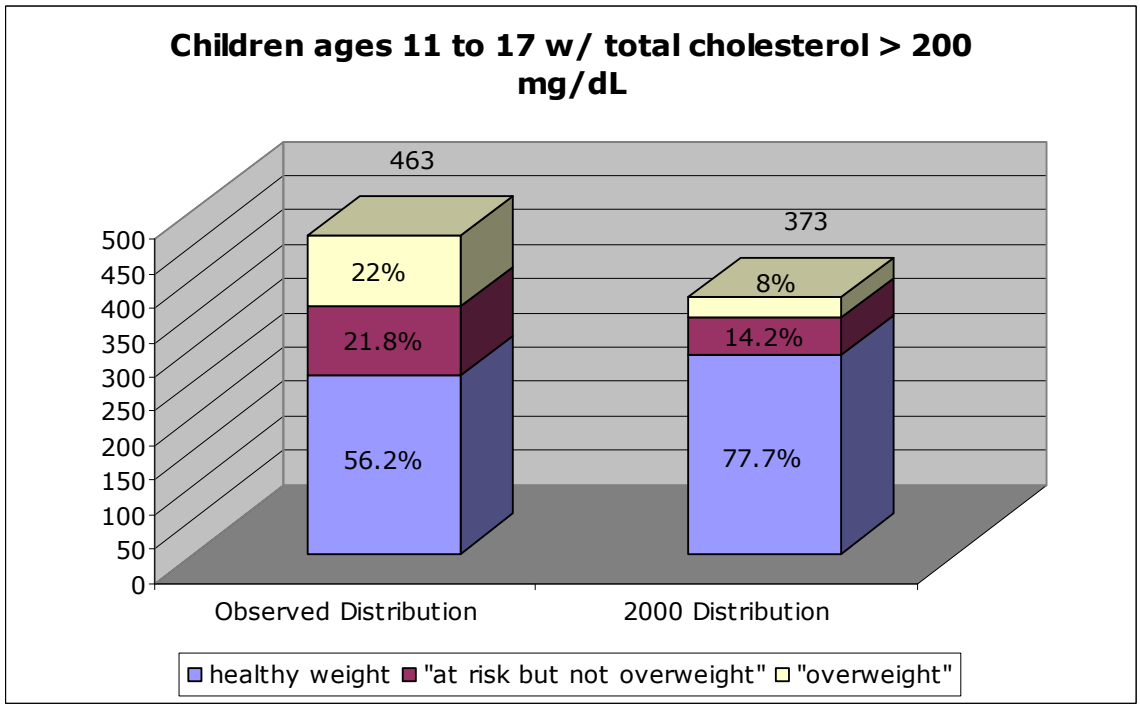


Figure XIII-15 Simulation comparison- Children ages 11 to 17 w/ triglycerides > 130 mg/dL

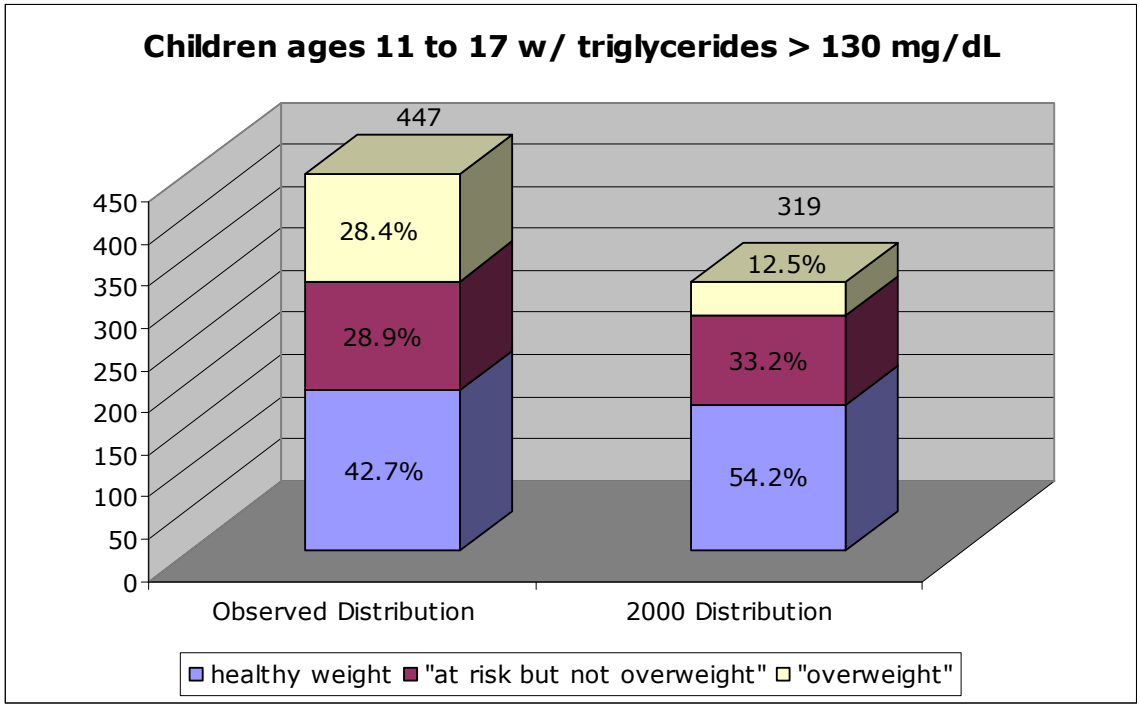


Figure XIII-16 Simulation comparison- Children ages 11 to 17 w/ low-density lipoprotein cholesterol > 130 mg/dL

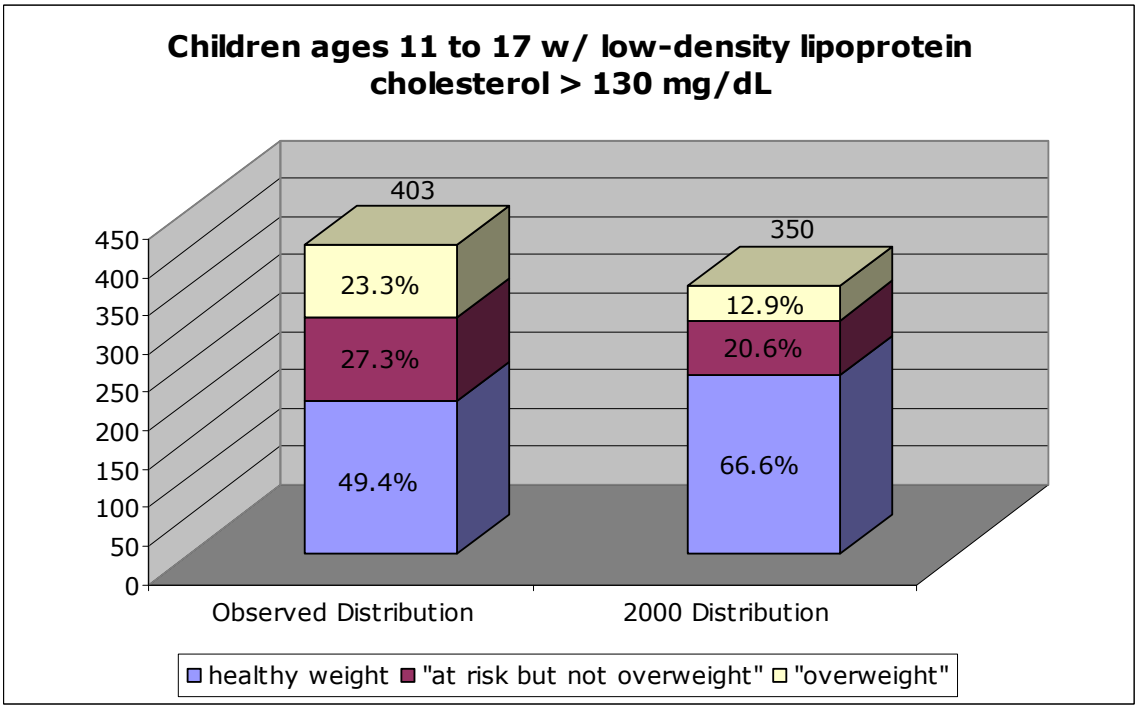


Figure XIII-17 Simulation comparison- Children ages 11 to 17 w/ high-density lipoprotein cholesterol < 35 mg/dL

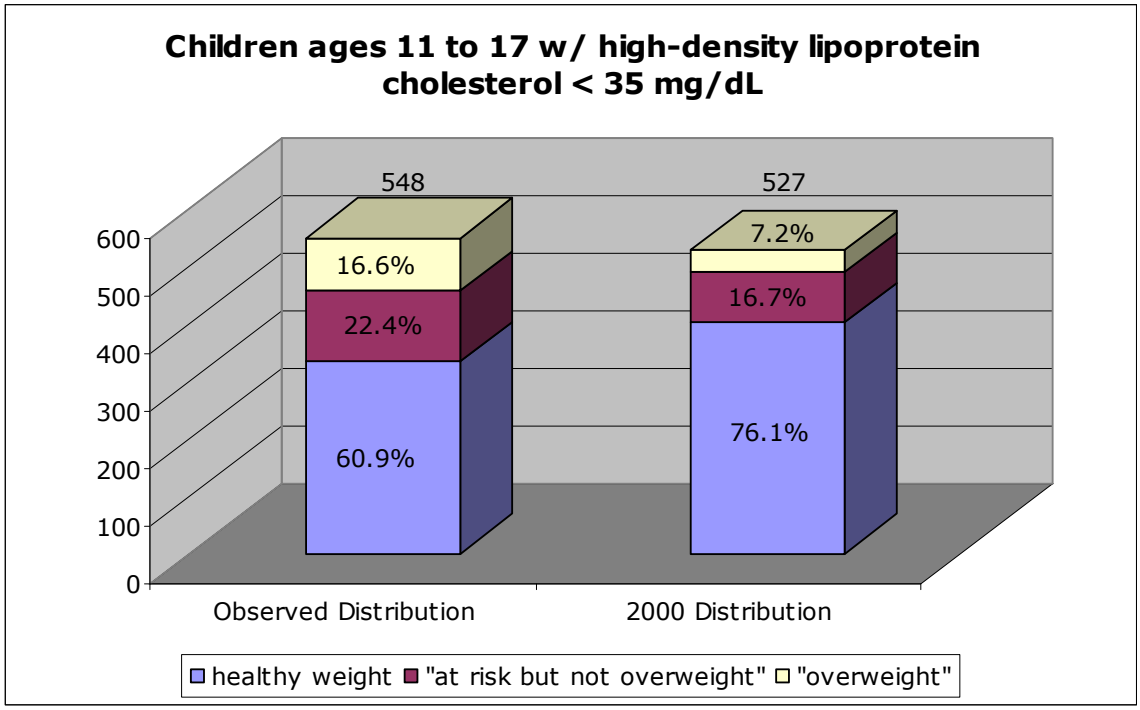


Figure XIII-18 Simulation comparison- Children ages 11 to 17 w/ fasting insulin > 95th percentile

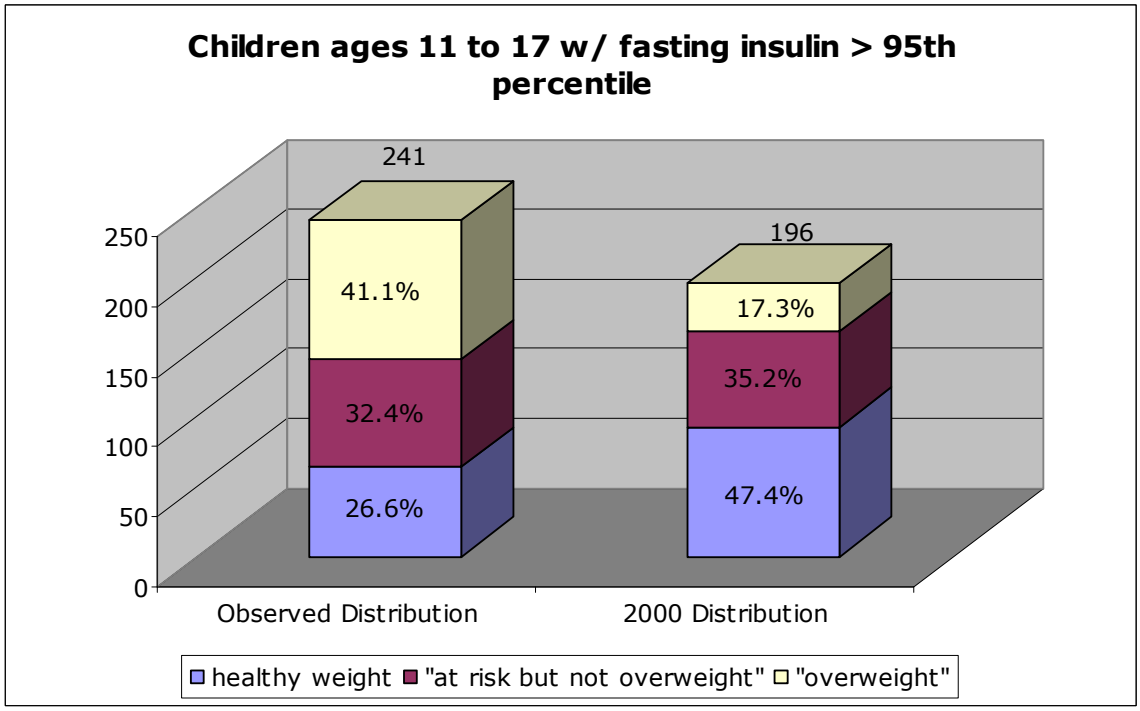


Figure XIII-19 Simulation comparison- Children ages 11 to 17 w/ systolic blood pressure > 95th percentile

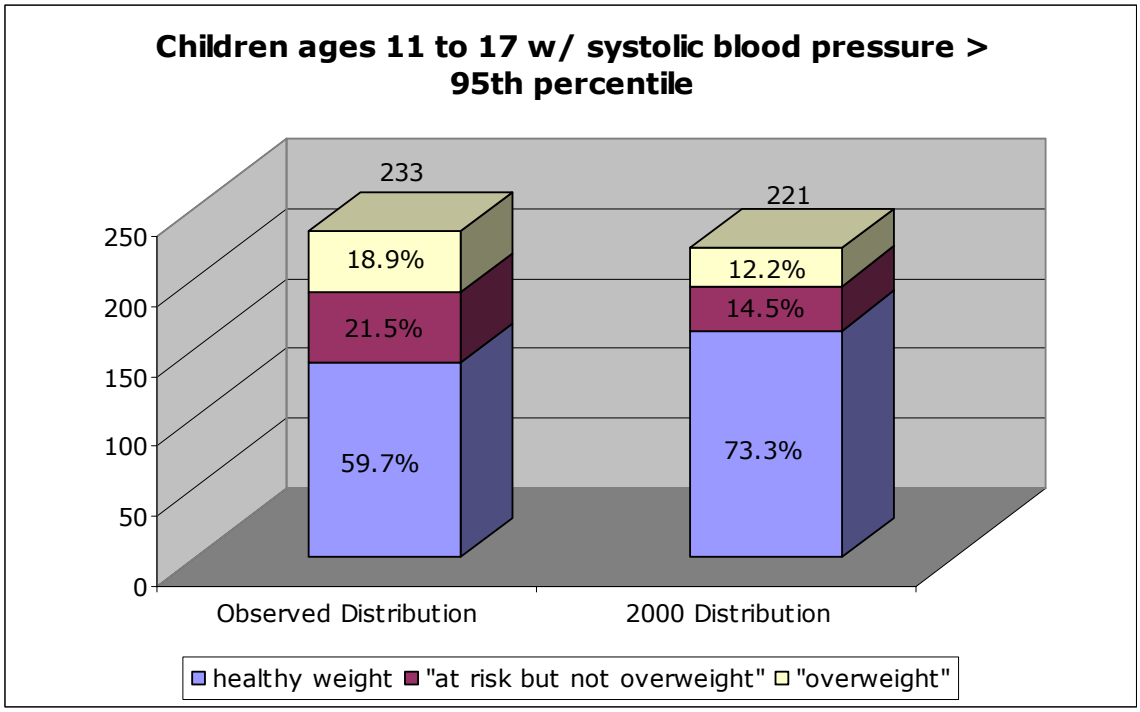


Figure XIII-20 Simulation comparison- Children ages 11 to 17 w/ diastolic blood pressure > 95th percentile

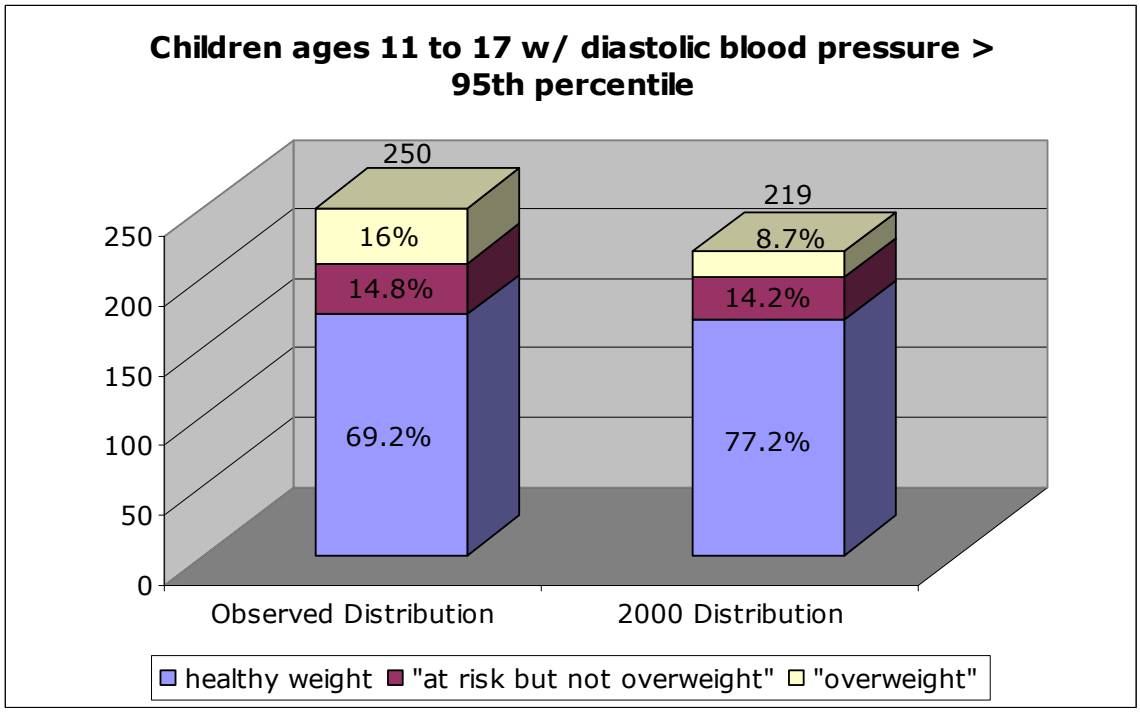


Figure XIII-21 Simulation comparison- Children ages 11 to 17 w/ 0 out of 7 risk factors

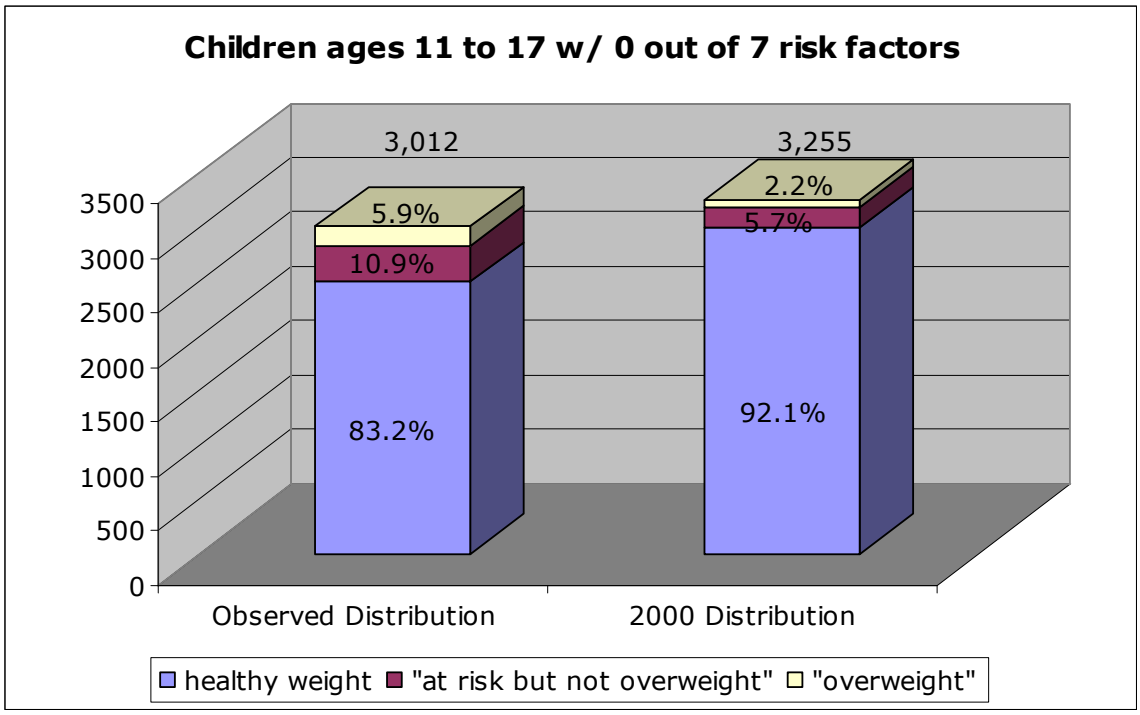


Figure XIIII-22 Simulation comparison- Children ages 11 to 17 w/ 1 out of 7 risk factors

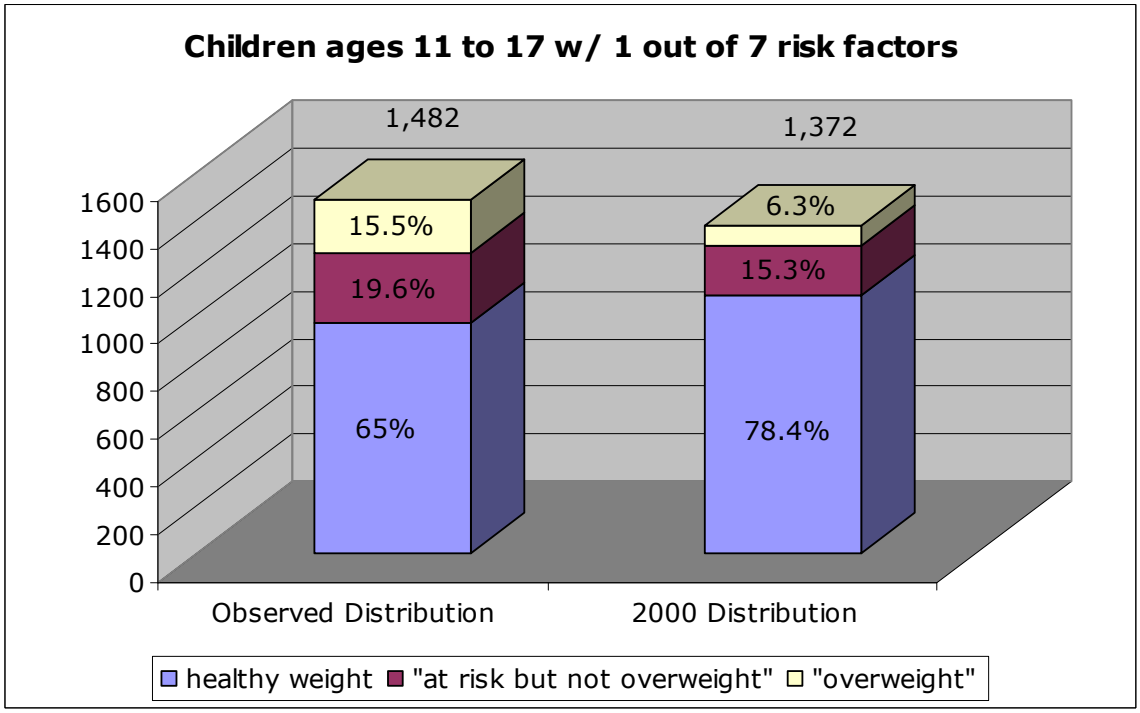


Figure XIIII-23 Simulation comparison- Children ages 11 to 17 w/ 2 out of 7 risk factors

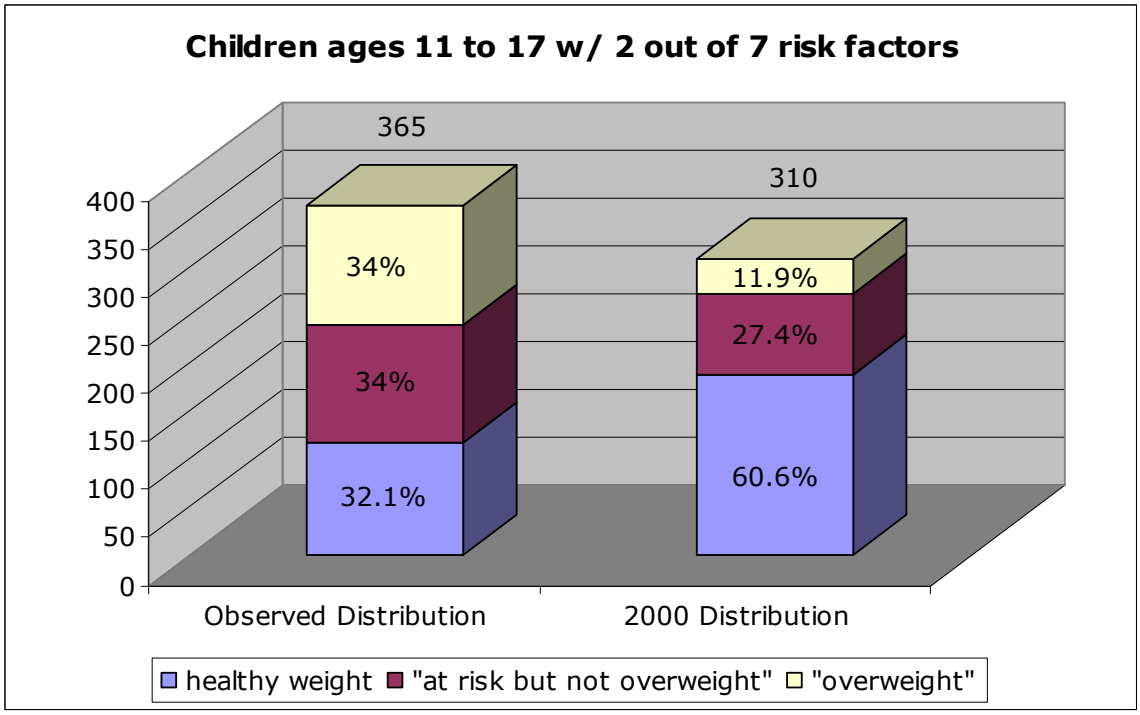


Figure XIIII-24 Simulation comparison- Children ages 11 to 17 w/ 3 out of 7 risk factors

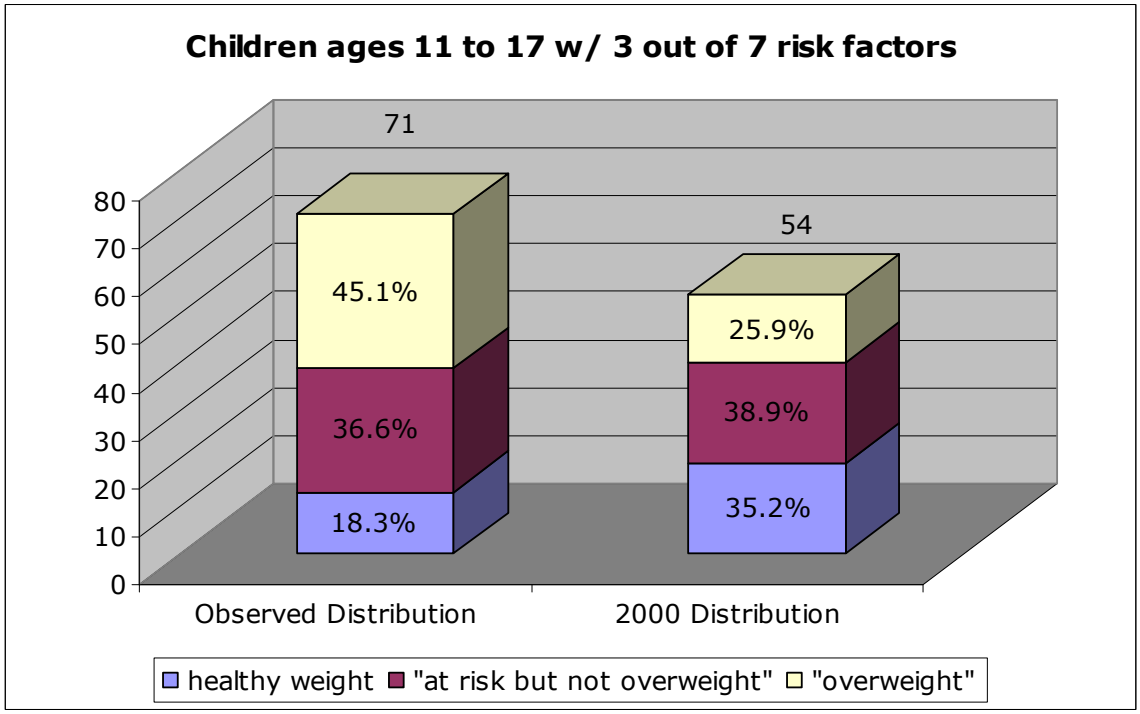


Figure XIIII-25 Simulation comparison- Children ages 11 to 17 w/ 4 out of 7 risk factors

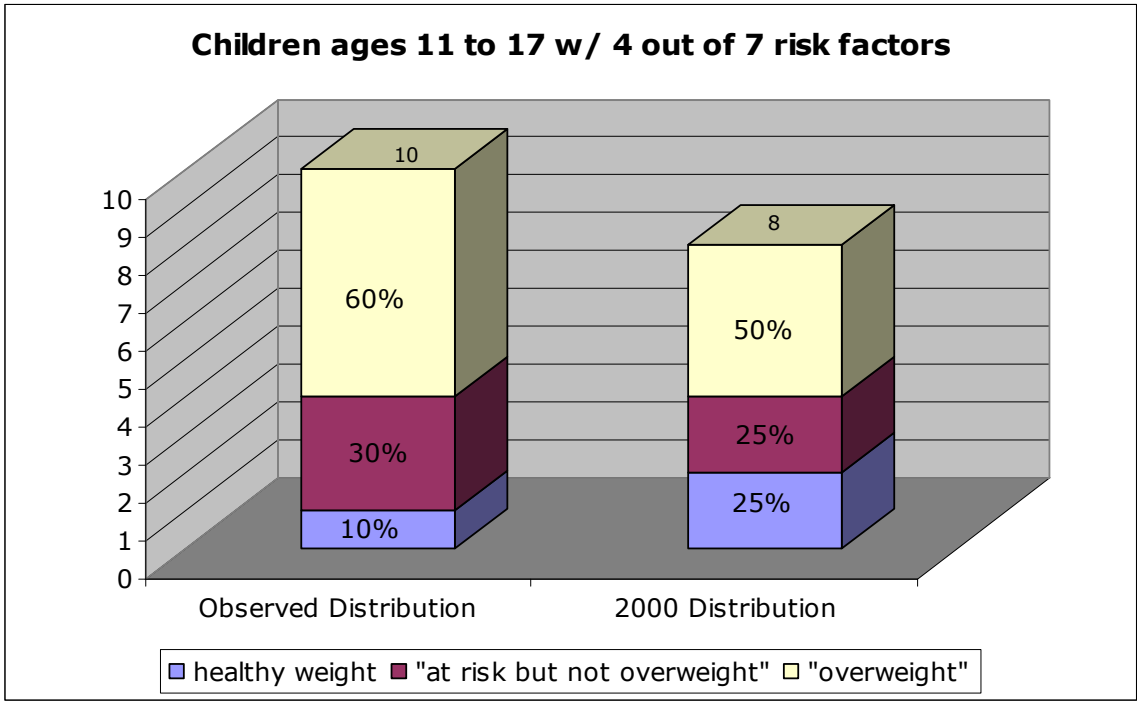
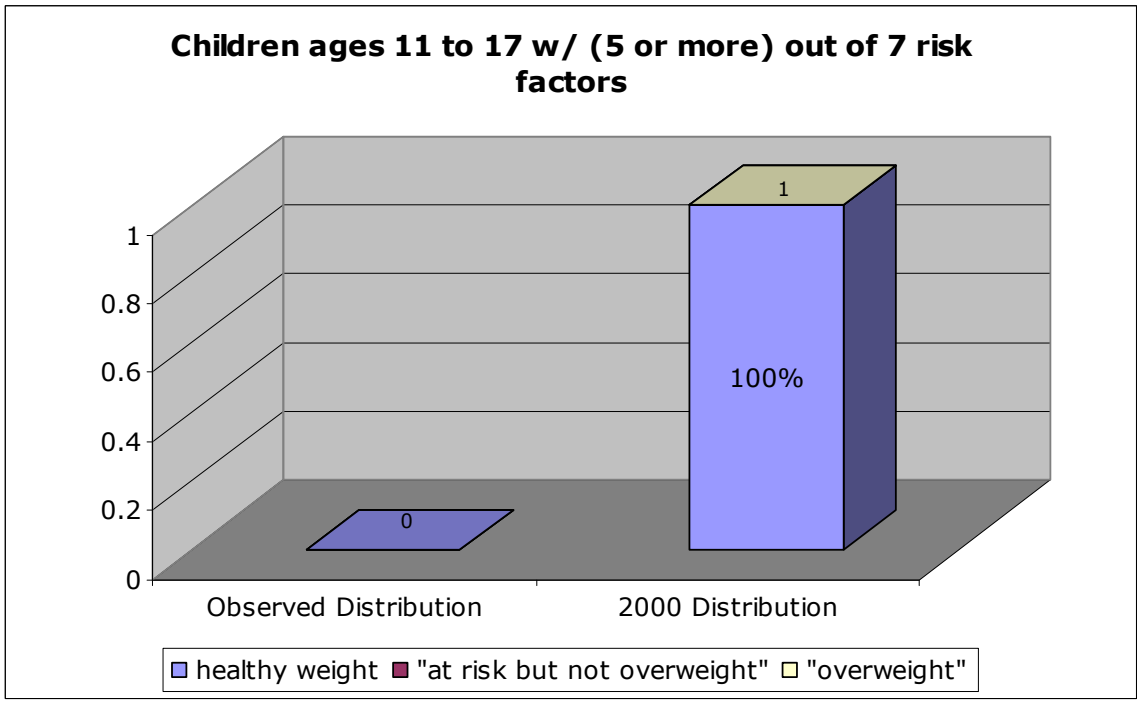



Figure XIIII-26 Simulation comparison- Children ages 11 to 17 w/ (5 or more) out of 7 risk factors