Summer 8-12-2014

# A Comparison of Anthropometric Measures for Classification of Metabolic Syndrome and Cardiometabolic Risk Factors, NHANES 2007-2010

John Heath

## ABSTRACT

**BACKGROUND:** Type 2 diabetes and cardiovascular disease (CVD) are among the leading causes of death in the United States. The Metabolic Syndrome, which comprises a cluster of cardiometabolic risk factors, puts individuals at increased risk for these diseases. It is therefore important that people with Metabolic Syndrome, at high risk for CVD and type 2 diabetes, are identified and treated. Since it may not often be practical to obtain the laboratory measures necessary for diagnosing the Metabolic Syndrome, simple anthropometric measures are a useful way of quickly identifying individuals at increased risk for the Metabolic Syndrome.
**OBJECTIVE:** The purpose of this thesis is to evaluate the utility of three of the most commonly used anthropometric measures – Body Mass Index (BMI), Waist Circumference (WC), and Waist-to-Height Ratio (WC) – for classifying individuals with and without the Metabolic Syndrome and its component risk factors in the United States. Using Receiver Operating Characteristic (ROC) curve analysis and Area Under the Curve (AUC) statistics, this thesis will assess the utility of each body measurement and compare it to BMI.
**METHODS:** A large, multi-ethnic, nationally representative sample from the National Health and Nutrition Examination Survey (NHANES) 2007-2010 was used for this analysis. The study sample was restricted to adults aged 20-65 with complete information on height, weight, waist circumference, blood pressure, HDL cholesterol, fasting glucose, and triglycerides (n=3,769). In order to compare the utility of different anthropometric measures for classification, weighted ROC curves were constructed for each anthropometric measure-outcome combination and AUC statistics were compared. AUC statistics were calculated by approximating the definite integral of the ROC curves with the trapezoidal rule. Variances for AUC statistics and differences in AUC statistics were estimated with jackknife repeated replication. Analyses were completed for the entire sample and separately for non-Hispanic whites, non-Hispanic blacks, and Mexican Americans.
**RESULTS:** For the entire sample, WC (AUC=0.752) did a better job than BMI (AUC=0.728) at classifying individuals with and without the Metabolic Syndrome ($p<0.001$) and all of the component risk factors except for HDL cholesterol. WHtR (AUC=0.740) performed better than BMI at classifying the Metabolic Syndrome ($p=0.048$), high blood pressure, and high triglycerides. The performance of WHtR was inconsistent across race. For every analysis in the overall sample and in the race subgroups, WC performed significantly better than BMI or no different from BMI, except for low HDL cholesterol among Mexican Americans where it performed significantly worse than BMI.
**CONCLUSION:** Waist circumference should be considered, especially over BMI, for risk stratification in clinical settings and research. Further research should attempt to identify optimum waist circumference cut points for use in the US population.

# A COMPARISON OF ANTHROPOMETRIC MEASURES FOR CLASSIFICATION OF METABOLIC SYNDROME AND CARDIOMETABOLIC RISK FACTORS, NHANES 2007-2010

By

John Wesley Heath

B.A., GEORGIA STATE UNIVERSITY

A Thesis Submitted to the Graduate Faculty
of Georgia State University in Partial Fulfillment
of the
Requirements for the Degree

MASTER OF PUBLIC HEALTH

ATLANTA, GEORGIA
30303

# A COMPARISON OF ANTHROPOMETRIC MEASURES FOR CLASSIFICATION OF METABOLIC SYNDROME AND CARDIOMETABOLIC RISK FACTORS, NHANES 2007-2010

By

John Wesley Heath

Approved:

_____
Committee Chair

_____
Committee Member

_____
Date

For Pop

## ACKNOWLEDGEMENTS

I would first like to thank Dr. Rodney Lyn and Dr. Richard Rothenberg for their support and understanding throughout the completion of this thesis. I would like to especially thank Dr. Rodney Lyn for the opportunity to work with him these last two years and for his guidance during the entirety of my graduate studies. Finally, I would like to thank all of my friends and family for their support over the past two years and especially both of my parents, without whom I could never be where I am today.

## AUTHOR'S STATEMENT

In presenting this thesis as a partial fulfillment of the requirements for an advanced degree from Georgia State University, I agree that the Library of the University shall make it available for inspection and circulation in accordance with its regulations governing materials of this type. I agree that permission to quote from, to copy from, or to publish this thesis may be granted by the author or, in his/her absence, by the professor under whose direction it was written, or in his/her absence, by the Associate Dean, School of Public Health. Such quoting, copying, or publishing must be solely for scholarly purposes and will not involve potential financial gain. It is understood that any copying from or publication of this dissertation which involves potential financial gain will not be allowed without written permission of the author.

_____

Signature of Author

**NOTICE TO BORROWERS**

All theses deposited in the Georgia State University Library must be used in accordance with the stipulations prescribed by the author in the preceding statement.

The author of this thesis is:
John Wesley Heath

The Chair of the committee for this thesis is:
Rodney Lyn

Users of this thesis who are not regularly enrolled as students at Georgia State University are required to attest acceptance of the preceding stipulation by signing below. Libraries borrowing this thesis for the use of their patrons are required to see that each user records here the information requested.

| NAME OF USER | ADDRESS | DATE | TYPE OF USE (EXAMINATION ONLY OR COPYING) |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

# John Wesley Heath

**4005 Oak Park Circle · Atlanta, GA 30324 · 404-915-1602 · jheath1@student.gsu.edu**

## EDUCATION

**Georgia State University,** Atlanta, GA — Expected August 2014
Master of Public Health: Epidemiology

**Georgia State University,** Atlanta, GA — May 2007
Bachelor of Arts: Anthropology

## EXPERIENCE

**Georgia State University,** Atlanta, GA — August 2012 – Present
*Graduate Research Assistant to Dr. Rodney Lyn*

- Conducted a variety of literature reviews and statistical analyses, including analyses of complex survey samples such as National Health and Nutrition Examination Survey (NHANES)
- Served as lead data analyst on contract project for non-profit organization

**Georgia Department of Public Health,** Atlanta, GA — May 2013 – August 2013
*Healthcare Associated Infections (HAIs) Intern*

- Managed, merged, and analyzed 13 datasets of up to 3,000 records of protected health information from the CDC's National Healthcare Safety Network HAI surveillance system to produce crude and standardized rates of HAIs in GA hospitals
- Produced 14 statistical tables and 45 figures for first ever quarterly report on GA HAIs, used internally by decision makers to inform HAI prevention efforts
- Developed software in R programming language still in use by state epidemiologists to automate production of custom statistical tables and figures for internal quarterly reports

**United States Peace Corps,** Paraguay — February 2010 – April 2012
*Rural Health Extension Volunteer*

- Conducted health census of 50 homes in local language of Guaraní and prepared written community needs assessment in Spanish

## TABLE OF CONTENTS

**Page**

ACKNOLEDGEMENTS ..... iv

LIST OF TABLES ..... ix

LIST OF ACRONYMS ..... x

CHAPTERS

1. INTRODUCTION ..... 1
   1.1 Background ..... 1
   1.2 Study Purpose ..... 1

2. REVIEW OF THE LITERATURE ..... 2
   2.1 CVD, Type II Diabetes Mellitus, and the Metabolic Syndrome ..... 2
   2.2 Diagnostic Criteria for the Metabolic Syndrome ..... 5
   2.3 Anthropometric Measures for Risk Classification ..... 7

3. METHODS ..... 10
   3.1 Study Purpose ..... 10
   3.2 Data Source ..... 10
   3.3 Study Sample ..... 11
   3.4 Variables ..... 11
   3.5 Statistical Analysis ..... 14

4. RESULTS ..... 17
   4.1 Descriptive Statistics ..... 17
   4.2 ROC Curves ..... 19
   4.3 AUC Statistics ..... 19

5. DISCUSSION AND CONCLUSION ..... 27

REFERENCES ..... 32

APPENDIX – ROC CURVES ..... 36

## LIST OF TABLES

**Page**

Table 1. Criteria for Metabolic Syndrome Diagnosis ……...…… 7

Table 2. Characteristics of Study Sample ……..…. 18

Table 3. AUC statistics and 95% Confidence Intervals, Overall …… 20

Table 4. AUC statistics and 95% Confidence Intervals, non-Hispanic whites ……... 22

Table 5. AUC statistics and 95% Confidence Intervals, non-Hispanic blacks ……...… 24

Table 6. AUC statistics and 95% Confidence Intervals, Mexican Americans ……..... 26

## LIST OF ACRONYMS

AUC – Area Under the Curve

BMI – Body Mass Index

CVD – Cardiovascular Disease

NHANES – National Health and Nutrition Examination Survey

ROC – Receiver Operating Characteristic

WC – Waist Circumference

WHtR – Waist to Height Ratio

# Chapter I

# INTRODUCTION

## 1.1 Background

Type 2 diabetes and cardiovascular disease (CVD) are among the leading causes of death in the United States (Murphy, Xu, & Kochanek, 2013; CDC, 2014). The Metabolic Syndrome, which comprises a cluster of cardiometabolic risk factors, puts individuals at increased risk for these diseases (Ford, Li, & Sattar, 2008; Gami et al., 2007). It is therefore important that people with Metabolic Syndrome, at high risk for CVD and type 2 diabetes, are identified and treated. Since it may not often be practical to obtain the laboratory measures necessary for diagnosing the Metabolic Syndrome, simple anthropometric measures are a useful way of quickly identifying individuals at increased risk for the Metabolic Syndrome and thus type 2 diabetes and CVD.

## 1.2 Study Purpose

The purpose of this thesis is to evaluate the utility of three of the most commonly used anthropometric measures – Body Mass Index (BMI), Waist Circumference (WC), and Waist-to-Height Ratio (WHtR) – for classifying individuals with and without the Metabolic Syndrome and its component risk factors. Using Receiver Operating Characteristic (ROC) curve analysis and Area Under the Curve (AUC) statistics, this thesis will assess the absolute utility of each body measurement and compare it to BMI which may be considered the gold standard for anthropometric measures.

# Chapter II

# REVIEW OF LITERATURE

## 2.1 Cardiovascular Disease, Type II Diabetes Mellitus, and the Metabolic Syndrome

CVD is the leading cause of death for both men and women in the United States, killing about 600,000 people every year (Murphy et al., 2013). The cost of health care services, medications, and lost productivity related to CVD in the US each year totals $108 billion (Heidenreich et al., 2011). In the US, morbidity and mortality related to CVD is highest among non-Hispanic blacks (CDC, 2005; Bauer, Briss, Goodman, & Bowman, 2014) and projections have indicated that this disparity will continue into the future (Heidenreich et al., 2011).

Type 2 diabetes was the seventh leading cause of death in the United States in 2010 and was listed as the underlying cause of death on 69,071 death certificates and mentioned as a cause of death on a total of 234,051 death certificates. Another 29.1 million people, or 9.3% of the United States population, are thought to be currently living with diabetes, 8.1 million of which are unaware of their diabetic status (CDC, 2014). Diabetes cost the United States $245 billion in direct and indirect medical costs in 2012 (CDC, 2014). Type 2 diabetes was previously referred to as adult-onset diabetes and is distinguished from type 1 diabetes, which was previously referred to as juvenile-onset diabetes. It's estimated that type 2 diabetes accounts for 90% to 95% of all diagnosed cases of diabetes (CDC, 2014). For the purposes of this thesis the term 'diabetes' will refer only to type 2 diabetes.

The prevalence of diabetes remained fairly constant in the US from 1980 through 1990 but has steadily increased since 1990 (CDC, 2012). The US also saw a dramatic nationwide increase in obesity between 1990 and 2010 (CDC, 2014). In 2010, it was projected that by 2050

as many as 1 in 3 adults in the United States could have diabetes if the current trend continues unabated (Boyle, Thompson, Gregg, Barker, & Williamson, 2010). There are also significant racial disparities in diabetes morbidity. From 2010 to 2012 in the United States it was estimated that among people aged 20 years or older, 13.2 % of non-Hispanic blacks and 12.8% of Hispanics had diagnosed diabetes compare to 7.6% of non-Hispanic whites; American Indians and Alaska Natives had the highest prevalence at 15.9% (CDC, 2014).

CVD and diabetes share a number of individual risk factors, including high blood pressure, dyslipidemia, and obesity (Smith, 2007). Increased fasting glucose is essentially the definition of prediabetes (CDC, 2014). Together, these risk factors – high blood pressure, dyslipidemia, increased fasting glucose, and obesity – compose the Metabolic Syndrome as it is currently defined by the International Diabetes Foundation (Alberti et al., 2009).

The concept of the Metabolic Syndrome was first proposed by Gerald Reaven in 1988 (Reaven, 1988). He termed it Syndrome X and implicated insulin resistance as the underlying cause. It was subsequently called many other things, but is now most commonly referred to as the Metabolic Syndrome. There has been much debate over the underlying cause of the Metabolic Syndrome. Earlier studies implicated insulin resistance (Ferrannini, Haffner, Mitchell, & Stern, 1991; Reaven, 1988), but more recently focus has turned to visceral, abdominal obesity and has shown it to be an independent predictor of insulin resistance as well as the other features of the Metabolic Syndrome (Carr et al., 2004; Wagenknecht et al., 2003).

Determining the underlying cause of the Metabolic Syndrome is beyond the scope of this thesis. It is generally agreed, however, that the Metabolic Syndrome is a clustering of interrelated metabolic risk factors that increase the risk of CVD and diabetes and that it increases the risk of diabetes more than it increases the risk of CVD (Ford et al., 2008; Gami et al., 2007).

Getting a clear picture of exactly how much the Metabolic Syndrome increases the risk for CVD and diabetes can be difficult as studies are often conducted among very different populations, using different diagnostic criteria, and with different outcomes of interest. However, meta-analyses have indicated that Metabolic Syndrome is associated with approximately 1.5 to 2 times the risk of incident CVD and CVD related death, even after controlling for traditional cardiovascular risk factors (Galassi, Reynolds, & He, 2006; Gami et al., 2007). The degree to which the Metabolic Syndrome increases the risk for diabetes depends on how many components of the syndrome an individual has. Risk increases with the number of components present and it has been shown that having 3 or 4 components of the Metabolic Syndrome may increase the risk for incident diabetes by over 10 or 20 times, depending on the combination of risk factors (Ford et al., 2008; Wilson, D'Agostino, Parise, Sullivan, & Meigs, 2005). Meta-analyses and other studies indicate that the Metabolic Syndrome increases the risk of incident diabetes by 3 to 7 times, and that this increase in risk is independent of other risk factors such as fasting insulin (Aschner, 2010; Ford et al., 2008; Hanley et al., 2005; Lorenzo et al., 2003). It was estimated that between 2003 and 2006 approximately 34% of adults 20 years of age and over had the Metabolic Syndrome; non-Hispanic black males were about half as likely to have the Metabolic Syndrome as non-Hispanic white males and non-Hispanic black and Mexican American females were about 1.5 times as likely to have the Metabolic Syndrome as non-Hispanic white females (Ervin, 2009).

The components of the Metabolic Syndrome – abdominal obesity, high blood pressure, low HDL cholesterol, high triglycerides, and high fasting glucose – are all cardiometabolic risk factors on their own and it has been suggested that the predictive ability of the Metabolic Syndrome for CVD and diabetes represents little more than the sum of its parts (Cameron et al.,

2007; Ford et al., 2008). However, Cameron et al. (2007) conducted their study with a sample of about 3,000 Mauritians, a population with relatively low waist circumference, and found that the waist circumference cut points for 2 of the 3 definitions of Metabolic Syndrome that they used did not perform well in that population. The third definition of Metabolic Syndrome used waist-to-hip ratio instead of waist circumference to define abdominal obesity, and using this definition the researchers did indeed find that individuals with the Metabolic Syndrome were at a 2 fold increased risk for diabetes, even when controlling for all the individual components of the Metabolic Syndrome.

The Metabolic Syndrome is of interest primarily because it helps to identify individuals who are at increased risk of both type 2 diabetes and CVD, despite whether it is more predictive of CVD and diabetes than the sum of its parts or it is simply a collection of cardiometabolic risk factors that tend to present together and confer additive risks to an individual. It is therefore important that individuals with this cluster of risk factors be identified for intervention and treatment. Several organizations have proposed diagnostic criteria for identifying these individuals.

## 2.2 Diagnostic Criteria for the Metabolic Syndrome

The first proposed diagnostic criteria came from the World Health Organization (WHO) and emphasized evidence of insulin resistance as a requirement for diagnosis of the Metabolic Syndrome (Alberti & Zimmet, 1998). The WHO criteria required an individual have insulin resistance plus two additional risk factors – obesity, hypertension, high triglycerides or reduced HDL cholesterol. In 2001, the National Cholesterol Education Program (NCEP) Adult Treatment Panel III (ATP III) released its own criteria for defining the Metabolic Syndrome

(NCEP ATP III, 2002). The ATP criteria did not require insulin resistance or any other single risk factor as necessary for diagnosis of the Metabolic Syndrome. Instead, NCEP suggested that the presence of 3 out of 5 risk factors – abdominal obesity, elevated triglycerides, low HDL cholesterol, elevated blood pressure, and elevated fasting glucose – be the basis for the diagnosis of Metabolic Syndrome. These risk factors were chosen as the basis for diagnosis because they were the components of Metabolic Syndrome that can most readily be measured through routine clinical evaluation, unlike insulin resistance and a proinflammatory state.

In 2005, the International Diabetes Federation (IDF) and the American Heart Association/National Heart, Lung, and Blood Institute (AHA/NHLBA) met to try to reconcile the different diagnostic criteria for the Metabolic Syndrome (Alberti, Zimmet, Shaw, & IDF Epidemiology Task Force Consensus Group, 2005). However, the recommendations that emerged from that meeting were still conflicting. The IDF agreed with the ATP III recommendations that insulin resistance not be required for a diagnosis, but recommended instead that abdominal obesity be required as 1 of 5 risk factors with the remaining four risk factors largely unchanged from the ATP III definitions. Under this definition, abdominal obesity plus 2 or more of the remaining 4 risk factors would constitute a diagnosis of Metabolic Syndrome. The IDF also suggested that waist circumference may provide a simple and useful screening tool for Metabolic Syndrome. The AHA/NHLBI recommendations were similar but did not require abdominal obesity for diagnosis. These organizations recently met again and agreed that waist circumference should not be required for diagnosis (Alberti et al., 2009). Therefore, the presence of 3 or more of 5 risk factors – abdominal obesity, high blood pressure, low HDL cholesterol, high triglycerides, and high fasting glucose – constitute one of the most recent and widely used definitions of Metabolic Syndrome. These recommendations also

include clinical cut points for determining whether each risk factor can be considered present in an individual. These cut points are displayed in Table 1 and are the cut points used for the purposes of this thesis. It has been pointed out that the 5 variables in this definition are not used as continuous variables but instead as risk factors that are either present or absent, which makes it a less than perfect tool for diagnosis; they cannot be used in the sort of risk calculator for CVD or diabetes that treats the variables continuously (Després et al., 2008).

**Table 1.** Criteria for Metabolic Syndrome Diagnosis

| Measure | Cut Points |
|---|---|
| Elevated waist circumference | Population specific cut points |
| High Blood Pressure | Systolic ≥ 130 and/or diastolic ≥ 85 mm Hg |
| Low HDL Cholesterol | <40 mg/dL in males; <50 mg/dL in females |
| High Triglycerides | ≥ 150 mg/dL |
| High Fasting Glucose | ≥ 100 mg/dL |

Criteria from (Alberti et al., 2009)

### 2.3 Anthropometric Measures for Risk Classification

It has long been known that obesity is associated with the risk factors that compose the Metabolic Syndrome, though it has been debated whether they are more closely associated with total absolute fat or abdominal obesity in particular (Kannel et al., 1991). Total absolute fat is most often assessed by Body Mass Index (BMI), whereas abdominal fat is most often assessed

with Waist Circumference (WC). Waist-to-height ratio (WHtR) has also been proposed as a measure of obesity that takes the bodily distribution of fat into account in a way that BMI does not. All three of these measures have been proposed as simple screening tools to identify individuals that may be at increased risk for the Metabolic Syndrome, its component risk factors, CVD, diabetes, or mortality. BMI has emerged as the measure most commonly used. Much work has been done to determine which body measurement is the most useful predictor (Ashwell, Gunn, & Gibson, 2012; Christian, Mochari, & Mosca, 2009; Czernichow, Kengne, Stamatakis, Hamer, & Batty, 2011; Huxley, Mendis, Zheleznyakov, Reddy, & Chan, 2010; Lee, Huxley, Wildman, & Woodward, 2008; van Dijk, Takken, Prinsen, & Wittink, 2012; Vazquez, Duval, Jacobs, & Silventoinen, 2007), although it is difficult to get a clear picture of which measurements perform best due to the varying methods and study populations. It has been demonstrated that the relationship between these anthropometric indices and cardiometabolic risk factors varies by race (Christian et al., 2009), which makes meta-analyses that include data from several different populations difficult to interpret.

A meta-analysis of over 82,000 British individuals from 9 cohorts found that greater WC was associated with increased risk of CVD mortality after controlling for traditional cardiometabolic risk factors and that BMI was not (Czernichow et al., 2011). Another meta-analysis that focused solely on the outcome of incident diabetes (Vazquez et al., 2007) analyzed data from 32 studies from around the world and found that the relative risks for incident diabetes were essentially the same for BMI and WC. However, other research has indicated that abdominal obesity is more important to the development of diabetes and suggests that WC is a stronger predictor of diabetes than BMI (Klein et al., 2007).

Yet another meta-analysis of 20 articles with data on over 45,000 European and US Caucasian men and women found that WC correlated more highly with blood pressure, triglycerides, and fasting blood glucose than did BMI or WHtR; for HDL cholesterol, the correlation with WC was about the same as BMI and both were more highly correlated than WHtR (Van Dijk et al., 2012). The authors therefore suggested that WC be used in clinical practice and research studies above BMI.

Perhaps most relevant to this thesis due to the similar research questions, outcomes, and methods of the studies included, Ashwell et al. (2012) conducted a meta-analysis of 31 primary studies from all over the world that used ROC curve analysis to compare the utility of WHtR against either BMI or WC in classifying individuals with diabetes, hypertension, and dyslipidemia, among other outcomes. They found that for all outcomes WHtR improved classification over BMI by 4-5% and that WC improved classification over BMI by 3%. This meta-analysis evaluated many of the same studies as an earlier meta-analysis by Lee et al. (2008) that reached similar conclusions. The authors therefore recommended that WHtR be considered as a screening tool before BMI and WC, as has been suggested before (Ashwell & Hsieh, 2005).

# Chapter III

# METHODS

## 3.1 Study Purpose

The purpose of this thesis is to determine which anthropometric measure – BMI, WC, or WHtR – is the best discriminator for detecting individuals with the Metabolic Syndrome and its components – high blood pressure, low HDL cholesterol, high triglycerides, and high fasting glucose – in a large, nationally representative, and multi-ethnic sample of adults in the United States.

## 3.2 Data Source

Data were obtained from the 2007-2008 and 2009-2010 cycles of the National Health and Nutrition Examination Survey (NHANES), a program of the National Center for Health Statistics. NHANES utilizes a large, multi-stage probability sample design to facilitate nationally representative estimates and collects data through a questionnaire, a physical examination, and laboratory testing. It is therefore used to set US national standards for measurements such as weight and blood pressure. This thesis uses data from the questionnaire, examination, and laboratory components of NHANES. Health interviews are conducted in respondents' homes while the examination and laboratory components are conducted is a mobile examination center (MEC). All data is collected by trained personnel.

## 3.3 Study Sample

From 2007-2010, NHANES collected data on 20,686 individuals. Only adults aged 20-65 with complete information on height, weight, waist circumference, blood pressure, HDL cholesterol, fasting glucose, and triglycerides were included in the sample for this thesis.

## 3.4 Variables

This thesis considered several anthropometric measures, all of which are continuous. The outcomes were also continuous, but were dichotomized for the purposes of this thesis. For example, each individual has a specific systolic blood pressure, but they have been dichotomized for this thesis as either having high blood pressure or not having high blood pressure. The cut points for the outcomes are clinical diagnosis criteria for the Metabolic Syndrome as proposed by the International Diabetes Federation Task Force on Epidemiology and Prevention, the National Heart, Lung, and Blood Institute, and the American Heart Association, among others (Alberti, 2009).

### *3.4.1 Body Mass Index (BMI)*

Height and weight were recorded for each individual during the mobile examination portion of the survey. Standing height was recorded in centimeters as each participant stood with their heels together against a straight backboard. Participants were weighed in kilograms with a digital scale while wearing only a standard gown and underpants. BMI was computed by dividing a participant's weight in kilograms by their height in meters squared.

### *3.4.2 Waist Circumference (WC)*

Waist circumference was measured in centimeters for each participant. Measurements were taken just above the uppermost lateral border of the right ilium.

### *3.4.3 Waist to Height Ratio (WHtR)*

Waist to height ratio was computed as waist circumference in centimeters divided by standing height in centimeters.

### *3.4.4 High Blood Pressure*

Systolic and diastolic blood pressure was recorded for participants 8 years and older during the MEC portion of the survey. Both were measured after the participant sat and rested quietly for 5 minutes. Three measurements were taken for both systolic and diastolic blood pressure, and if one measurement was incomplete then a fourth measurement was taken. For this thesis, an individual's systolic and diastolic blood pressure was computed as the mean of all non-missing measurements.

Individuals were classified as having high blood pressure if they met one of three criteria: systolic blood pressure greater than or equal to 130, diastolic blood pressure greater than or equal to 85, or if they've been told by a doctor that they have hypertension and are currently taking medication to control their blood pressure. Individuals that did not meet one of these three criteria were classified as not having high blood pressure.

### *3.4.5 Low HDL Cholesterol (HDL)*

HDL cholesterol was measured in mg/dL for all NHANES participants 6 years and older. Blood was drawn and HDL levels were determined by Roche Modular P chemistry analyzer.

Males with HDL cholesterol less than 40 mg/dL and females with HDL cholesterol less than 50 mg/dL were classified as having low HDL.

### *3.4.6 High Fasting Glucose*

Fasting glucose was recorded in mg/dL for a subsample of NHANES participants 12 years and older that were examined during the morning MEC session. Eligible participants also had to have fasted for at least 9 hours prior to examination. Blood was drawn and fasting glucose levels were determined by Roche Modular P chemistry analyzer. Individuals that had hemophilia, that were taking medication for diabetes, and that had not fasted for at least 9 hours prior to the examination were excluded.

Individuals were classified as having high fasting glucose if they had fasting glucose greater than or equal to 100 mg/dL or if they had been told by a doctor that they have diabetes or prediabetes and reported currently taking medication to lower blood sugar.

### *3.4.7 High Triglycerides*

Triglycerides were measured in mg/dL for a subsample of participants 12 years and older that were examined during the morning MEC session. Blood was drawn and triglyceride levels were determined by Roche Modular P chemistry analyzer.

Individuals were classified as having high triglycerides if they had triglycerides greater than or equal to 150 mg/dL.

*3.4.8 Metabolic Syndrome*

Under the definition used for this thesis (Alberti et al., 2009), the Metabolic Syndrome is diagnosed on the basis of having 3 of the following 5 risk factors: abdominal obesity, high blood pressure, low HDL, high fasting glucose, and high triglycerides. Since measures of obesity are being used to classify individuals, the Metabolic Syndrome is defined here as having at least 2 of the remaining 4 risk factors, similar to the old IDF definition before the requirement for abdominal obesity was dropped (Alberti et al., 2005).

## 3.5 Statistical Analysis

In order to compare the utility of different anthropometric measures for classifying individuals, each measure was considered as a screening test for the presence of the Metabolic Syndrome and its component risk factors. For each of these tests empirical ROC curves were constructed and AUC statistics were compared. Therefore, an ROC curve was constructed for each body measurement-outcome combination. Sampling weights provided by NHANES were used in the construction of the ROC curves. Individuals that were tested for fasting glucose and triglycerides and that were required to fast before the MEC session were a smaller subsample of the larger MEC sample, so unique sampling weights are provided for analyses restricted to that subsample of individuals. The fasting subsample weights were used for all analyses in this thesis.

Many standard statistical packages that construct ROC curves do not take into account sampling weights. For this thesis, weighted contingency tables were constructed for each relevant cut point of the body measurement. The weighted counts in these tables allowed for the calculation of sensitivity and specificity at each cut point. The sensitivity was then plotted

against 1-specificity to create the ROC curves. AUC statistics were calculated by approximating the definite integral of the ROC curves with the trapezoidal rule.

Standard methods for estimating the variance of AUC statistics do not take into account survey design or sampling weights. Variances for the AUC statistics and differences in AUC statistics were estimated with jackknife repeated replication (Wolter, 2007). In a stratified cluster design, jackknife repeated replication works by dropping out one primary sampling unit (PSU) at a time and reweighting the remaining PSUs in that stratum. In a stratum with 2 PSUs, the weights for one PSU will be set to zero and the weights for the other PSU will be multiplied by 2. In a stratum with 3 PSUs, the weights for one PSU will be set to zero and the weights for the others will be multiplied by 1.5. This process is repeated for each PSU, resulting in as many replicates as there are PSUs in the sample. The sample for this thesis contained 63 PSUs. Thus, 63 replicates were constructed, each with its own set of weights. A separate estimate is then produced for each replicate, resulting in 63 estimates. The variation in these estimates is the basis for estimating the standard error of the statistic: the sum of the squared differences between the full sample estimate of the statistic and each replicate estimate is divided by a factor that depends on the number of PSUs in that stratum.

AUC statistics and 95% confidence intervals were calculated for each combination of body measurement and risk factor. Within each risk factor, the AUC statistics for each body measurement were compared to the AUC statistic for BMI, which was the reference, by subtracting the AUC for BMI from the AUC for each other measurement. Thus, a negative difference indicates that BMI had a larger AUC statistic and a positive difference indicates that BMI had a smaller AUC statistic. The statistical significance of these differences was calculated with a standard t-test; the estimated difference in AUC statistics was divided by the standard

error of that difference, as estimated with jackknife repeated replication. The resulting statistic has a Student's t distribution with degrees of freedom equal to the number of clusters in the sample minus the number of strata, in this case 63-31=32 (Heeringa, West, and Berglund, 2010).

One overall analysis was conducted that included males and females of all races and separate analyses were conducted for the three races with the largest sample size in NHANES, non-Hispanic whites, non-Hispanic blacks, and Mexican Americans. All analyses were conducted in the R statistical computing environment version 3.0.3 (R Core Team, 2014) with the survey package (Lumley, 2012).

# Chapter IV

# RESULTS

## 4.1 Descriptive Statistics

Demographic characteristics, frequencies for the outcomes, and summary statistics for the anthropometric measures are displayed in Table 2. All reported frequencies are unweighted. There were 3,769 total observations in the study sample. This was reduced from 20,686 in the total NHANES 2007-2010 sample. Many observations were removed from analysis because of the 20-65 age restriction, but many more were removed because the fasting sub-sample with data on fasting glucose and triglycerides was a small subset of the overall sample.

Forty-two percent (42%) of the sample was between the ages of 20 and 39, 45% was between 40 and 59, and 13% was between 60 and 65. The sample was almost evenly split between male (51%) and female (48%). Non-hispanic whites were the largest group (43%) and the rest of the sample was approximately equal parts non-Hispanic black (19%), Mexican American (21%), and other or multi-racial (17%).

High blood-pressure (33%), low HDL cholesterol (31%), and high triglycerides (29%) were each present in about a third of the sample. High fasting glucose (48%) and the Metabolic Syndrome (43%) were present in almost half of the sample. BMI ranged from about 15 $kg/m^2$ to about 85 $kg/m^2$ with a mean of 29 $kg/m^2$; WC ranged from about 59 cm to 167 cm with a mean of 98 cm; and WHtR ranged from 0.37 to 1.03 with a mean of 0.58.

**Table 2.** Characteristics of Study Sample (n=3,769)

| Variable | N | % | Minimum | Mean | Maximum | SD |
|---|---|---|---|---|---|---|
| Age | | | | | | |
| 20-39 | 1,594 | 42 | | | | |
| 40-59 | 1,697 | 45 | | | | |
| 60-65 | 478 | 13 | | | | |
| Sex | | | | | | |
| Male | 1,833 | 51 | | | | |
| Female | 1,936 | 48 | | | | |
| Race | | | | | | |
| Non-Hispanic White | 1,612 | 43 | | | | |
| Non-Hispanic Black | 720 | 19 | | | | |
| Mexican American | 791 | 21 | | | | |
| Other/Multi-Racial | 646 | 17 | | | | |
| High Blood Pressure | | | | | | |
| Yes | 1,232 | 33 | | | | |
| No | 2,537 | 67 | | | | |
| Low HDL | | | | | | |
| Yes | 1,170 | 31 | | | | |
| No | 2,599 | 69 | | | | |
| High Fasting Glucose | | | | | | |
| Yes | 1,826 | 48 | | | | |
| No | 1,943 | 52 | | | | |
| High Triglycerides | | | | | | |
| Yes | 1,079 | 29 | | | | |
| No | 2,690 | 71 | | | | |
| Metabolic Syndrome | | | | | | |
| Yes | 1,616 | 43 | | | | |
| No | 2,153 | 57 | | | | |
| BMI | | | 15.02 | 29.00 | 84.87 | 6.69 |
| WC | | | 59.10 | 98.14 | 167.00 | 15.99 |
| WHtR | | | 0.37 | 0.58 | 1.03 | 0.10 |

*Frequencies are unweighted and are not representative of US population

## 4.2 ROC Curves

All weighted, empirical ROC curves are presented in the Appendix. For the overall sample and within each race subgroup, the diagnostic utility of WC, WHtR, and BMI are compared for the Metabolic Syndrome and each component outcome. On the curve for BMI, the cut points corresponding to a BMI of 25 and a BMI of 30 are indicated as a reference since these are traditional BMI cut points for classifying overweight and obesity, respectively, and increased cardiometabolic risk.

## 4.3 AUC Statistics

### *4.3.1 Overall*

AUC statistics, 95% confidence intervals, and p values for comparing the diagnostic performance of WC and WHtR to BMI are reported in Table 3 for the entire sample (n=3,769). WC performed better than BMI at classifying individuals with and without the Metabolic Syndrome ($p<0.001$) and all of the component risk factors except for HDL cholesterol. WHtR performed better than BMI at classifying Metabolic Syndrome ($p=0.048$), high blood pressure ($p=0.006$), and high triglycerides ($p=0.007$). Neither WC nor WHtR performed better than BMI at classifying low HDL cholesterol. WHtR performed no better than BMI at classifying high fasting glucose.

**Table 3.** AUC statistics and 95% Confidence Intervals, Overall (n=3,769)

| | AUC | Lower 95% CI | Upper 95% CI | p |
|---|---|---|---|---|
| Blood Pressure | | | | |
| BMI | 0.682 | 0.650 | 0.714 | |
| WC | 0.703 | 0.675 | 0.731 | 0.001 |
| WHtR | 0.694 | 0.667 | 0.722 | 0.006 |
| | | | | |
| HDL Cholesterol | | | | |
| BMI | 0.671 | 0.639 | 0.702 | |
| WC | 0.663 | 0.635 | 0.691 | 0.105 |
| WHtR | 0.674 | 0.641 | 0.708 | 0.461 |
| | | | | |
| Fasting Glucose | | | | |
| BMI | 0.664 | 0.634 | 0.695 | |
| WC | 0.698 | 0.667 | 0.728 | <0.001 |
| WHtR | 0.674 | 0.645 | 0.703 | 0.123 |
| | | | | |
| Triglycerides | | | | |
| BMI | 0.656 | 0.632 | 0.679 | |
| WC | 0.677 | 0.654 | 0.699 | 0.001 |
| WHtR | 0.676 | 0.652 | 0.700 | 0.007 |
| | | | | |
| Metabolic Syndrome | | | | |
| BMI | 0.728 | 0.699 | 0.757 | |
| WC | 0.752 | 0.724 | 0.780 | <0.001 |
| WHtR | 0.740 | 0.711 | 0.769 | 0.048 |

*4.3.2 Non-Hispanic Whites*

AUC statistics, 95% confidence intervals, and p values for comparing the diagnostic performance of WC and WHtR to BMI are reported in Table 4 for non-Hispanic whites (n=1,612). Among non-Hispanic whites, WC performed better than BMI at classifying the Metabolic Syndrome ($p=0.038$) and at classifying high fasting glucose ($p<0.001$). WC did slightly better than BMI at classifying high blood pressure and high triglycerides and slightly worse than BMI at classifying low HDL cholesterol, but none of these differences were quite statistically significant at the 95% confidence level. WHtR was not significantly different from BMI at classifying Metabolic Syndrome or any of the component risk factors.

**Table 4**. AUC statistics and 95% Confidence Intervals, non-Hispanic whites (n=1,612)

| | AUC | Lower 95% CI | Upper 95% CI | p |
|---|---|---|---|---|
| Blood Pressure | | | | |
| BMI | 0.702 | 0.660 | 0.744 | |
| WC | 0.716 | 0.678 | 0.754 | 0.079 |
| WHtR | 0.712 | 0.676 | 0.748 | 0.117 |
| | | | | |
| HDL Cholesterol | | | | |
| BMI | 0.680 | 0.637 | 0.724 | |
| WC | 0.669 | 0.628 | 0.709 | 0.068 |
| WHtR | 0.676 | 0.631 | 0.721 | 0.523 |
| | | | | |
| Fasting Glucose | | | | |
| BMI | 0.675 | 0.632 | 0.718 | |
| WC | 0.707 | 0.665 | 0.749 | <0.001 |
| WHtR | 0.680 | 0.639 | 0.721 | 0.472 |
| | | | | |
| Triglycerides | | | | |
| BMI | 0.670 | 0.634 | 0.706 | |
| WC | 0.683 | 0.647 | 0.719 | 0.081 |
| WHtR | 0.685 | 0.649 | 0.721 | 0.148 |
| | | | | |
| Metabolic Syndrome | | | | |
| BMI | 0.742 | 0.701 | 0.783 | |
| WC | 0.757 | 0.717 | 0.797 | 0.038 |
| WHtR | 0.744 | 0.703 | 0.784 | 0.830 |

*4.3.3 Non-Hispanic Blacks*

AUC statistics, 95% confidence intervals, and p values for comparing the diagnostic performance of WC and WHtR to BMI are reported in Table 5 for non-Hispanic blacks (n=720). Among non-Hispanic blacks, WC performed better than BMI at classifying the Metabolic Syndrome ($p<0.001$) and every component risk factor, except for low HDL cholesterol where a slightly better performance was not statistically significant ($p=0.090$). WHtR was significantly better than BMI at classifying Metabolic Syndrome ($p<0.001$), and every component risk factor except for high triglycerides.

**Table 5**. AUC statistics and 95% Confidence Intervals, non-Hispanic blacks (n=720)

| | AUC | Lower 95% CI | Upper 95% CI | p |
|---|---|---|---|---|
| Blood Pressure | | | | |
| BMI | 0.628 | 0.572 | 0.685 | |
| WC | 0.666 | 0.608 | 0.724 | <0.001 |
| WHtR | 0.659 | 0.603 | 0.715 | 0.002 |
| HDL Cholesterol | | | | |
| BMI | 0.662 | 0.598 | 0.726 | |
| WC | 0.679 | 0.626 | 0.733 | 0.090 |
| WHtR | 0.688 | 0.634 | 0.741 | 0.043 |
| Fasting Glucose | | | | |
| BMI | 0.634 | 0.590 | 0.677 | |
| WC | 0.676 | 0.630 | 0.722 | <0.001 |
| WHtR | 0.656 | 0.608 | 0.703 | 0.009 |
| Triglycerides | | | | |
| BMI | 0.606 | 0.554 | 0.659 | |
| WC | 0.640 | 0.589 | 0.690 | 0.036 |
| WHtR | 0.618 | 0.566 | 0.670 | 0.394 |
| Metabolic Syndrome | | | | |
| BMI | 0.705 | 0.671 | 0.738 | |
| WC | 0.748 | 0.715 | 0.781 | <0.001 |
| WHtR | 0.739 | 0.705 | 0.773 | <0.001 |

*4.3.4 Mexican Americans*

AUC statistics, 95% confidence intervals, and p values for comparing the diagnostic performance of WC and WHtR to BMI are reported in Table 6 for Mexican Americans (n=791). Among Mexican Americans, WC performed better than BMI at classifying the Metabolic Syndrome (p=0.001), high blood pressure (p<0.001), and high triglycerides (p=0.001). WC performed significantly worse than BMI at classifying low HDL cholesterol (p=0.017) and slightly better than BMI at classifying high fasting glucose, though this was not statistically significant (p=0.061). WHtR was not statistically significantly different from BMI for Metabolic Syndrome or any of the risk factors. The performance of WHtR was slightly better than BMI for the Metabolic Syndrome (p=0.094), high blood pressure (p=0.055), and high triglycerides (p=0.065), but none of these were quite statistically significant at the 95% confidence level.

**Table 6.** AUC statistics and 95% Confidence Intervals, Mexican Americans (n=791)

| | AUC | Lower 95% CI | Upper 95% CI | p |
|---|---|---|---|---|
| Blood Pressure | | | | |
| BMI | 0.666 | 0.624 | 0.708 | |
| WC | 0.713 | 0.672 | 0.753 | <0.001 |
| WHtR | 0.694 | 0.658 | 0.730 | 0.055 |
| | | | | |
| HDL Cholesterol | | | | |
| BMI | 0.687 | 0.648 | 0.726 | |
| WC | 0.665 | 0.621 | 0.708 | 0.017 |
| WHtR | 0.679 | 0.641 | 0.717 | 0.375 |
| | | | | |
| Fasting Glucose | | | | |
| BMI | 0.647 | 0.608 | 0.687 | |
| WC | 0.666 | 0.625 | 0.706 | 0.061 |
| WHtR | 0.652 | 0.612 | 0.692 | 0.663 |
| | | | | |
| Triglycerides | | | | |
| BMI | 0.639 | 0.596 | 0.681 | |
| WC | 0.669 | 0.636 | 0.702 | 0.001 |
| WHtR | 0.659 | 0.617 | 0.701 | 0.065 |
| | | | | |
| Metabolic Syndrome | | | | |
| BMI | 0.715 | 0.681 | 0.748 | |
| WC | 0.741 | 0.707 | 0.775 | 0.001 |
| WHtR | 0.732 | 0.700 | 0.764 | 0.094 |

# Chapter V

## DISCUSSION AND CONCLUSION

In the complete sample, which is representative of the US adult population aged 20-65, WC did a better job than BMI at classifying individuals with and without the Metabolic Syndrome and all of the component risk factors except for HDL cholesterol. For HDL cholesterol, there was no significant difference between WC and BMI. WC did a better job than BMI at classifying individuals with and without the Metabolic Syndrome across all of the race subgroups as well. The utility of WC in classifying the component risk factors varied a bit between races. For the most part, WC performed better at classifying the component risk factors among non-Hispanic blacks and Mexican Americans. However, among whites it only performed better than BMI at classifying high fasting glucose. In summary, for every analysis in the overall sample and in the race subgroups, WC performed significantly better than BMI or no different from BMI, except for low HDL cholesterol among Mexican Americans where it performed significantly worse than BMI.

WHtR performed significantly better than BMI at classifying individuals with and without the Metabolic Syndrome in the entire sample and among non-Hispanic blacks. Among non-Hispanic whites and Mexican Americans, WHtR was not significantly different from BMI at classifying the Metabolic Syndrome. Results were mixed for the component risk factors. In the full sample, WHtR performed better than BMI at classifying high blood pressure and high triglycerides. Among non-Hispanic blacks, WHtR performed better than BMI at classifying high blood pressure, low HDL cholesterol, and high fasting glucose. However, WHtR was not

significantly different from BMI at classifying any of the risk factors among non-Hispanic whites and Mexican Americans.

The results of this thesis differ slightly from the results of the meta-analysis by Ashwell et al. (2012) who found that WHtR performed better than WC and BMI at classifying various outcomes, including the Metabolic Syndrome, dyslipidemia, and hypertension. This meta-analysis reviewed 31 articles that used methods similar to the methods for this thesis and that reported AUC statistics. However, out of the 31 studies included in the meta-analysis, only 2 were conducted in the US population and one of those only included women. The authors also point out that before their meta-analysis it was difficult to prove the utility of WHtR over WC in populations without a lot of variability in height and that 15 of the studies included the meta-analysis were conducted among Asian populations that tend to have shorter average heights.

Of the 2 studies conducted in the US and included in Ashwell et al.'s meta-analysis (2012), one found that among US women WHtR and WC performed nearly identically at classifying CVD and that both were superior to BMI (Page et al., 2009). This thesis reached fairly similar conclusions, though the outcomes in this thesis were cardiometabolic risk factors and not CVD itself and the sample in this thesis consisted of both men and women. The other study, using an older sample of US adults from NHANES, did not compare WHtR and WC directly but found that WHtR and WC performed similarly at classifying diabetes and that both performed better than BMI (Li, Ford, Zhao, Kahn, & Mokdad, 2010). In contrast, this thesis found that WC performed significantly better than BMI at classifying high fasting glucose while WHtR did not. However, this thesis used a lower cut point to define high fasting glucose and classified individuals who had been told by a doctor that they had diabetes and were taking medication to lower their blood sugar as having high fasting glucose as well.

The results of this thesis also differ with the meta-analysis of Lee et al. (2008) which concluded that WHtR was the best anthropometric measure for classifying hypertension, diabetes, and dyslipidemia. However, the 10 studies in the Lee et al. (2008) meta-analysis were all included in the Ashwell et al. (2012) meta-analysis and none of them were conducted in the US population.

The results of this thesis largely concur with the conclusions reached by Van Dijk et al. (2012) in their meta-analysis. They reviewed articles that used different methods than this thesis and examined the correlation coefficients between anthropometric measurements and risk factors including high blood pressure, low HDL cholesterol, high triglycerides, and high fasting glucose. Twenty studies were reviewed, including 4 of which were conducted in US populations. They found that WC was more highly correlated with these risk factors than either WHtR or BMI.

The results of this thesis suggest that in a large, multi-ethnic, and nationally representative sample of US adults aged 20-65, WC is superior to BMI at classifying the Metabolic Syndrome as well as many of its component risk factors. This thesis did not explicitly test the statistical significance of differences between WC and WHtR. However, WC performed better than BMI more often than WHtR performed better than BMI across the outcomes and race subgroups. In many cases, WC performed significantly better than BMI where WHtR did not. In some cases, both WC and WHtR performed better than BMI but WC performed slightly better. These results are also largely in agreement with similar studies conducted in the US population. The few discrepancies between this thesis and previous research are likely due to different study populations, different methods, and/or different outcome definitions. These results also fit in with the current thinking that abdominal obesity is a stronger risk factor for the Metabolic Syndrome than is body mass.

When looking at the results for classifying the Metabolic Syndrome in the overall sample, the differences between the AUC for BMI (0.728) and the AUCs for WC (0.752) and WHtR (0.74) do not appear to be especially large, but it must be remembered that the ultimate utility of using an anthropometric measure for classification depends on the cut point chosen for that anthropometric measure. It is useful to examine the ROC curves and to consider a hypothetical scenario to illustrate the magnitude of these differences. Using this sample, the weighted estimate of the number of adults aged 20-65 with Metabolic Syndrome in the US between 2007 and 2010 is 67,296,904. Suppose a BMI of 25 (overweight) was used as a cut point to screen this entire population so that individuals with a BMI of 25 or greater were then assessed for the Metabolic Syndrome. This BMI cut point would result in a specificity of 0.442 and a sensitivity of 0.863 and would identify 58,066,617 true positives. If WC was instead used for the screening with a cut point of 89 cm, this would result in an almost identical specificity of 0.448 and a sensitivity of 0.882 which would identify 59,373,231 true positives. Since the specificities are nearly identical, the two measures would identify approximately the same amount of true negatives, but WC would identify over 1.3 million more true positives than BMI.

Again, the selection of appropriate cut points will largely determine how exactly these measures perform in practice, but the results of this thesis demonstrate that across the range of all possible cut points, WC performs better than BMI. Currently, it is recommended that different WC cut points be used in different populations and it is not entirely clear which cut points may be optimal (Alberti et al., 2009). Further research should attempt to determine optimum WC cut points for risk classification in the US population. The performance of these anthropometric measures and the cut points that are chosen likely vary by sex as well. One limitation of this thesis is that analyses were not conducted by sex in an effort to preserve large sample sizes. The

clinical performance of WC would also of course depend on how WC is measured exactly and whether or not patients will allow it. How to find and measure the waist is not always totally clear. Measuring a patient's WC is also slightly more invasive than measuring a patient's BMI in that it requires close physical contact from the physician. This may make certain patients less willing to consent to measurement.

Of course, screening the entire adult US population to identify those at risk for the Metabolic Syndrome would be difficult, so primary prevention for the Metabolic Syndrome, CVD, and diabetes remains crucial. Public health must ensure that prevention efforts for these diseases continue, especially in vulnerable populations. In the case of cardiovascular disease, the American Heart Association has noted that primary and secondary prevention efforts are often lacking in disadvantaged communities and has recommended the dissemination and implementation of effective prevention strategies in these communities (Heidenreich et al., 2011). Improving diagnostic screening tools to identify those with the Metabolic Syndrome and at risk for CVD and diabetes can and should be a part of these primary and secondary prevention strategies but will not alone be sufficient to control increasing prevalence of CVD and diabetes.

This thesis has shown that WC is a better screening tool than BMI for identifying individuals at increased risk of the Metabolic Syndrome. WHtR also performs better than BMI in many cases, though its performance is less consistent, especially across ethnicities. WHtR also does not perform as well as WC at classifying high fasting glucose which is critical for diabetes prevention efforts. WC should therefore be considered, over WHtR and especially over BMI, for risk stratification in clinical settings and research in the US adult population.

## REFERENCES


Alberti, K. G. M. M., Eckel, R. H., Grundy, S. M., Zimmet, P. Z., Cleeman, J. I., Donato, K. A., International Association for the Study of Obesity. (2009). Harmonizing the metabolic syndrome: a joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. Circulation, 120(16), 1640–1645. doi:10.1161/CIRCULATIONAHA.109.192644

Alberti, K. G. M. M., Zimmet, P., Shaw, J., & IDF Epidemiology Task Force Consensus Group. (2005). The metabolic syndrome--a new worldwide definition. Lancet, 366(9491), 1059–1062. doi:10.1016/S0140-6736(05)67402-8

Alberti, K. G., & Zimmet, P. Z. (1998). Definition, diagnosis and classification of diabetes mellitus and its complications. Part 1: diagnosis and classification of diabetes mellitus provisional report of a WHO consultation. Diabetic Medicine: A Journal of the British Diabetic Association, 15(7), 539–553. doi:10.1002/(SICI)1096-9136(199807)15:7<539::AID-DIA668>3.0.CO;2-S

Aschner, P. (2010). Metabolic syndrome as a risk factor for diabetes. Expert Review of Cardiovascular Therapy, 8(3), 407–412. doi:10.1586/erc.10.13

Ashwell, M., Gunn, P., & Gibson, S. (2012). Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis. Obesity Reviews: An Official Journal of the International Association for the Study of Obesity, 13(3), 275–286. doi:10.1111/j.1467-789X.2011.00952.x

Ashwell, M., & Hsieh, S. D. (2005). Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity. International Journal of Food Sciences and Nutrition, 56(5), 303–307. doi:10.1080/09637480500195066

Bauer, U. E., Briss, P. A., Goodman, R. A., & Bowman, B. A. (2014). Prevention of chronic disease in the 21st century: elimination of the leading preventable causes of premature death and disability in the USA. Lancet, 384(9937), 45–52. doi:10.1016/S0140-6736(14)60648-6

Boyle, J. P., Thompson, T. J., Gregg, E. W., Barker, L. E., & Williamson, D. F. (2010). Projection of the year 2050 burden of diabetes in the US adult population: dynamic modeling of incidence, mortality, and prediabetes prevalence. Population Health Metrics, 8, 29. doi:10.1186/1478-7954-8-29

Cameron, A. J., Zimmet, P. Z., Soderberg, S., Alberti, K. G. M. M., Sicree, R., Tuomilehto, J., Shaw, J. E. (2007). The metabolic syndrome as a predictor of incident diabetes mellitus in Mauritius. Diabetic Medicine: A Journal of the British Diabetic Association, 24(12), 1460–1469. doi:10.1111/j.1464-5491.2007.02288.x

Carr, D. B., Utzschneider, K. M., Hull, R. L., Kodama, K., Retzlaff, B. M., Brunzell, J. D., Kahn, S. E. (2004). Intra-abdominal fat is a major determinant of the National Cholesterol Education Program Adult Treatment Panel III criteria for the metabolic syndrome. Diabetes, 53(8), 2087–2094.

CDC - A Diabetes Report Card for the United States Quality of care in the 1990s - Publications - Diabetes DDT. (2012). Retrieved July 18, 2014, from http://www.cdc.gov/diabetes/pubs/reportcard.htm

Centers for Disease Control and Prevention. (2014). National Diabetes Statistics Report: Estimates of Diabetes and Its Burden in the United States, 2014.

Centers for Disease Control and Prevention (CDC). (2005). Health disparities experienced by black or African Americans--United States. MMWR. Morbidity and Mortality Weekly Report, 54(1), 1–3.

Christian, A. H., Mochari, H., & Mosca, L. J. (2009). Waist circumference, body mass index, and their association with cardiometabolic and global risk. Journal of the Cardiometabolic Syndrome, 4(1), 12–19. doi:10.1111/j.1559-4572.2008.00029.x

Czernichow, S., Kengne, A.-P., Stamatakis, E., Hamer, M., & Batty, G. D. (2011). Body mass index, waist circumference and waist-hip ratio: which is the better discriminator of cardiovascular disease mortality risk?: evidence from an individual-participant meta-analysis of 82 864 participants from nine cohort studies. Obesity Reviews: An Official Journal of the International Association for the Study of Obesity, 12(9), 680–687. doi:10.1111/j.1467-789X.2011.00879.x

Després, J.-P., Lemieux, I., Bergeron, J., Pibarot, P., Mathieu, P., Larose, E., Poirier, P. (2008). Abdominal obesity and the metabolic syndrome: contribution to global cardiometabolic risk. Arteriosclerosis, Thrombosis, and Vascular Biology, 28(6), 1039–1049. doi:10.1161/ATVBAHA.107.159228

Ervin, R. B. (2009). Prevalence of metabolic syndrome among adults 20 years of age and over, by sex, age, race and ethnicity, and body mass index: United States, 2003-2006. National Health Statistics Reports, (13), 1–7.

Ferrannini, E., Haffner, S. M., Mitchell, B. D., & Stern, M. P. (1991). Hyperinsulinaemia: the key feature of a cardiovascular and metabolic syndrome. Diabetologia, 34(6), 416–422.

Ford, E. S., Li, C., & Sattar, N. (2008). Metabolic syndrome and incident diabetes: current state of the evidence. Diabetes Care, 31(9), 1898–1904. doi:10.2337/dc08-0423

Galassi, A., Reynolds, K., & He, J. (2006). Metabolic syndrome and risk of cardiovascular disease: a meta-analysis. The American Journal of Medicine, 119(10), 812–819. doi:10.1016/j.amjmed.2006.02.031

Gami, A. S., Witt, B. J., Howard, D. E., Erwin, P. J., Gami, L. A., Somers, V. K., & Montori, V. M. (2007). Metabolic syndrome and risk of incident cardiovascular events and death: a systematic review and meta-analysis of longitudinal studies. Journal of the American College of Cardiology, 49(4), 403–414. doi:10.1016/j.jacc.2006.09.032

Grundy, S. M., Cleeman, J. I., Daniels, S. R., Donato, K. A., Eckel, R. H., Franklin, B. A., Costa, F. (2005). Diagnosis and Management of the Metabolic Syndrome An American Heart Association/National Heart, Lung, and Blood Institute Scientific Statement. Circulation, 112(17), 2735–2752. doi:10.1161/CIRCULATIONAHA.105.169404

Hanley, A. J. G., Karter, A. J., Williams, K., Festa, A., D'Agostino, R. B., Wagenknecht, L. E., & Haffner, S. M. (2005). Prediction of type 2 diabetes mellitus with alternative definitions of the metabolic syndrome: the Insulin Resistance Atherosclerosis Study. Circulation, 112(24), 3713–3721. doi:10.1161/CIRCULATIONAHA.105.559633

Heeringa, S. G., West, B. T., & Berglund, P. A. (2010). Applied Survey Data Analysis. CRC Press.

Heidenreich, P. A., Trogdon, J. G., Khavjou, O. A., Butler, J., Dracup, K., Ezekowitz, M. D., Council on Cardiovascular Surgery and Anesthesia, and Interdisciplinary Council on Quality of Care and Outcomes Research. (2011). Forecasting the future of cardiovascular disease in the United States: a policy statement from the American Heart Association. Circulation, 123(8), 933–944. doi:10.1161/CIR.0b013e31820a55f5

Huxley, R., Mendis, S., Zheleznyakov, E., Reddy, S., & Chan, J. (2010). Body mass index, waist circumference and waist:hip ratio as predictors of cardiovascular risk--a review of the literature. European Journal of Clinical Nutrition, 64(1), 16–22. doi:10.1038/ejcn.2009.68

Kannel, W. B., Cupples, L. A., Ramaswami, R., Stokes, J., Kreger, B. E., & Higgins, M. (1991). Regional obesity and risk of cardiovascular disease; the Framingham Study. Journal of Clinical Epidemiology, 44(2), 183–190.

Klein, S., Allison, D. B., Heymsfield, S. B., Kelley, D. E., Leibel, R. L., Nonas, C., American Diabetes Association. (2007). Waist circumference and cardiometabolic risk: a consensus statement from shaping America's health: Association for Weight Management and Obesity Prevention; NAASO, the Obesity Society; the American Society for Nutrition; and the American Diabetes Association. Diabetes Care, 30(6), 1647–1652. doi:10.2337/dc07-9921

Lee, C. M. Y., Huxley, R. R., Wildman, R. P., & Woodward, M. (2008). Indices of abdominal obesity are better discriminators of cardiovascular risk factors than BMI: a meta-analysis. Journal of Clinical Epidemiology, 61(7), 646–653. doi:10.1016/j.jclinepi.2007.08.012

Li, C., Ford, E. S., Zhao, G., Kahn, H. S., & Mokdad, A. H. (2010). Waist-to-thigh ratio and diabetes among US adults: the Third National Health and Nutrition Examination Survey. Diabetes Research and Clinical Practice, 89(1), 79–87. doi:10.1016/j.diabres.2010.02.014

Lorenzo, C., Okoloise, M., Williams, K., Stern, M. P., Haffner, S. M., & San Antonio Heart Study. (2003). The metabolic syndrome as predictor of type 2 diabetes: the San Antonio heart study. Diabetes Care, 26(11), 3153–3159.

Lumley, T. (2012) "survey: analysis of complex survey samples". R package version 3.28-2.

Murphy, S. L., Xu, J., & Kochanek, K. D. (2013). Deaths: final data for 2010. National Vital Statistics Reports: From the Centers for Disease Control and Prevention, National Center for Health Statistics, National Vital Statistics System, 61(4), 1–117.

National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III). (2002). Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) final report. Circulation, 106(25), 3143–3421.

NHANES - About the National Health and Nutrition Examination Survey. Retrieved June 26, 2014, from http://www.cdc.gov/nchs/nhanes/about_nhanes.htm

Page, J. H., Rexrode, K. M., Hu, F., Albert, C. M., Chae, C. U., & Manson, J. E. (2009). Waist-height ratio as a predictor of coronary heart disease among women. Epidemiology (Cambridge, Mass.), 20(3), 361–366. doi:10.1097/EDE.0b013e31819f38f1

R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/

Reaven, G. M. (1988). Banting lecture 1988. Role of insulin resistance in human disease. Diabetes, 37(12), 1595–1607.

Smith, S. C. (2007). Multiple risk factors for cardiovascular disease and diabetes mellitus. The American Journal of Medicine, 120(3 Suppl 1), S3–S11. doi:10.1016/j.amjmed.2007.01.002

Van Dijk, S. B., Takken, T., Prinsen, E. C., & Wittink, H. (2012). Different anthropometric adiposity measures and their association with cardiovascular disease risk factors: a meta-analysis. Netherlands Heart Journal: Monthly Journal of the Netherlands Society of Cardiology and the Netherlands Heart Foundation, 20(5), 208–218. doi:10.1007/s12471-011-0237-7

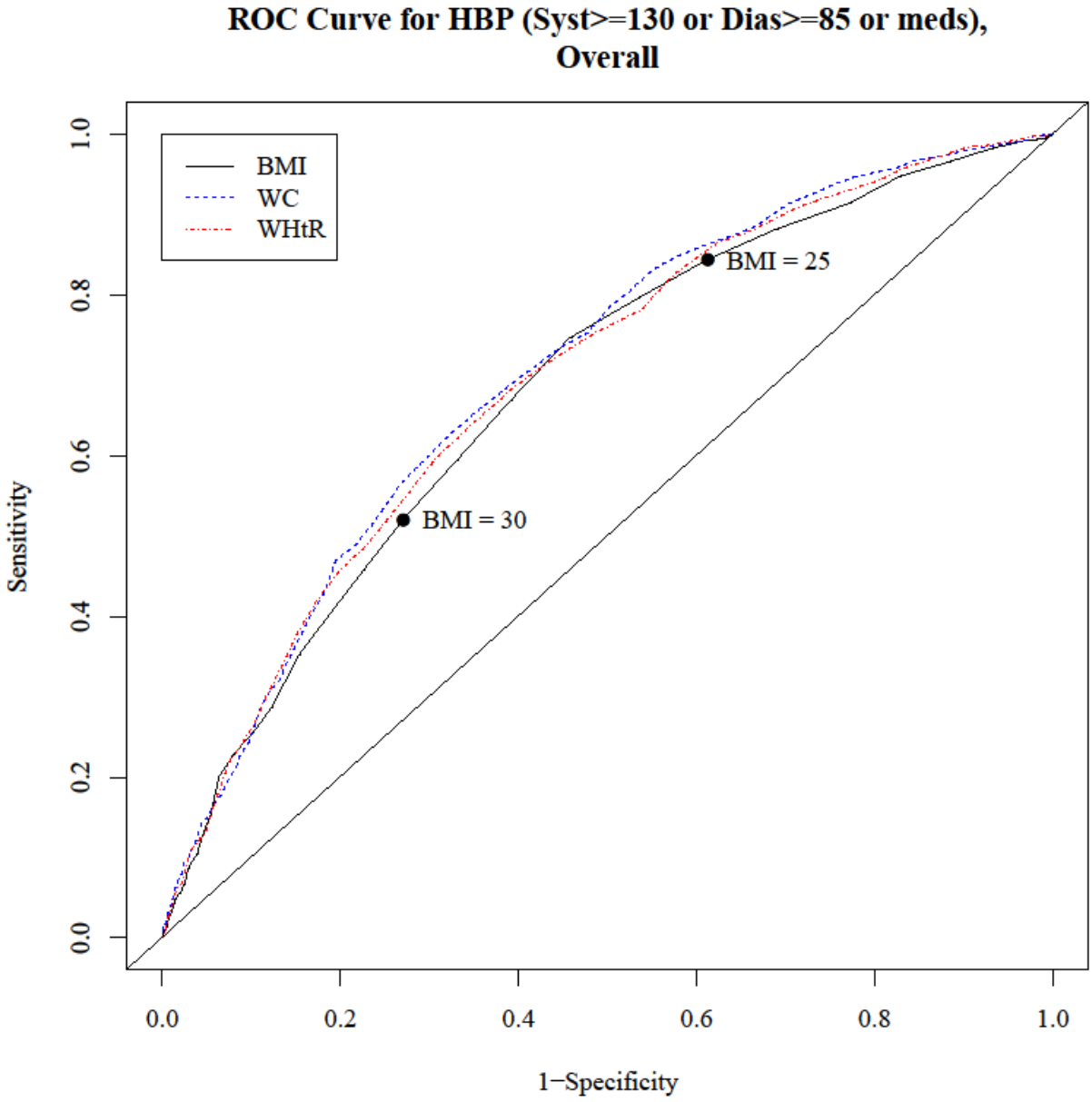
Vazquez, G., Duval, S., Jacobs, D. R., & Silventoinen, K. (2007). Comparison of body mass index, waist circumference, and waist/hip ratio in predicting incident diabetes: a meta-analysis. Epidemiologic Reviews, 29, 115–128. doi:10.1093/epirev/mxm008

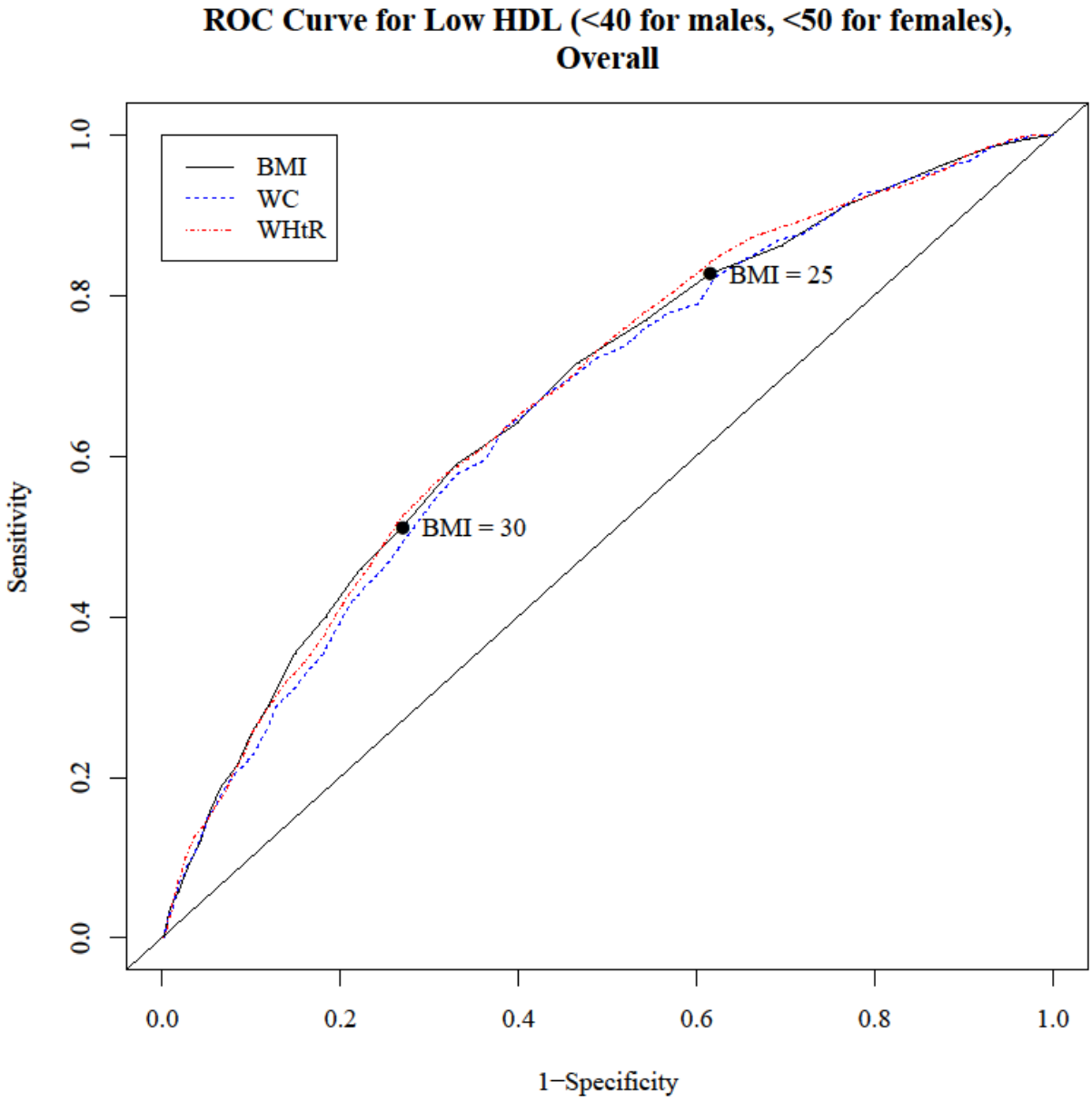
Wagenknecht, L. E., Langefeld, C. D., Scherzinger, A. L., Norris, J. M., Haffner, S. M., Saad, M. F., & Bergman, R. N. (2003). Insulin sensitivity, insulin secretion, and abdominal fat: the Insulin Resistance Atherosclerosis Study (IRAS) Family Study. Diabetes, 52(10), 2490–2496.

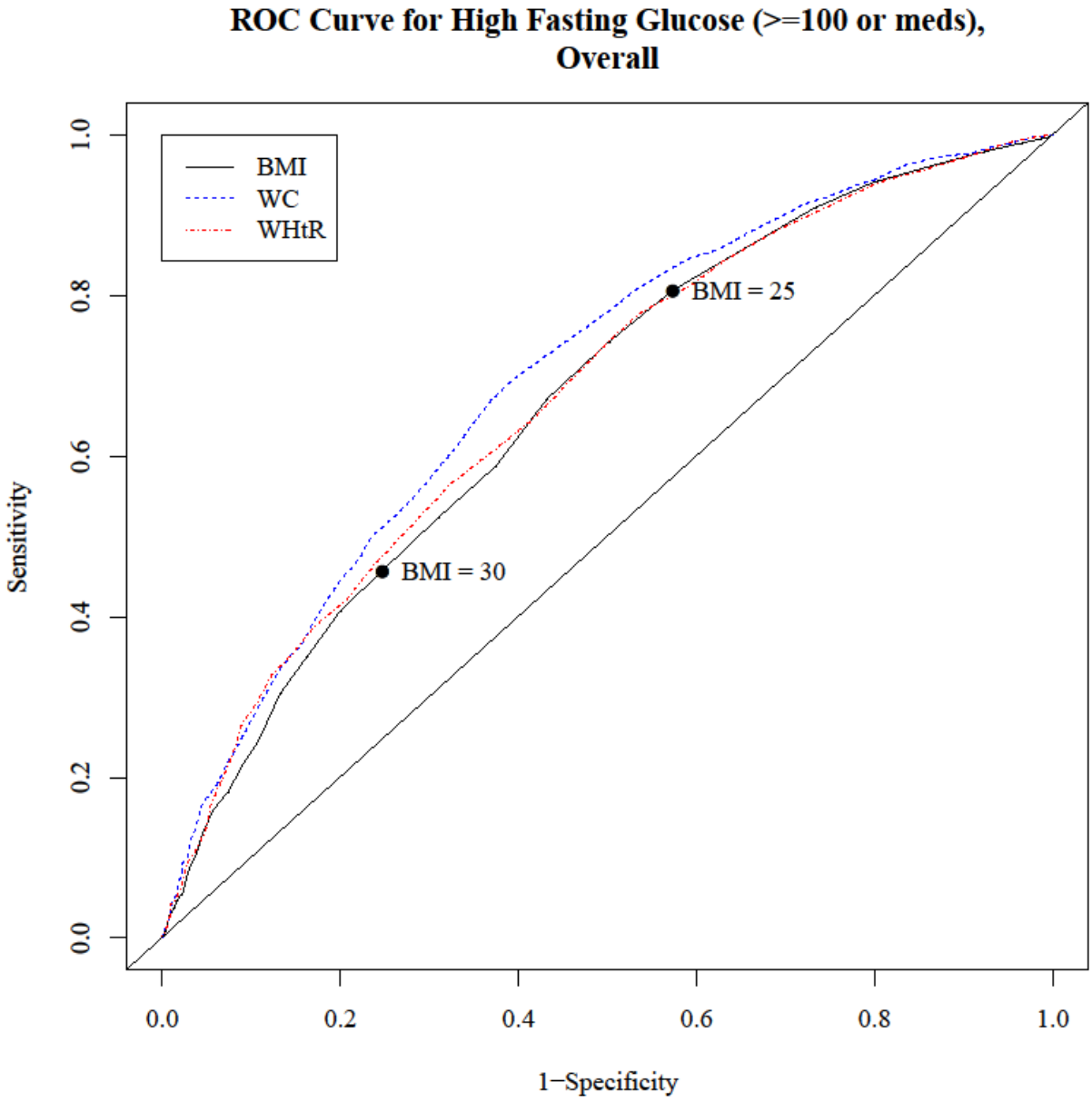
Wilson, P. W. F., D'Agostino, R. B., Parise, H., Sullivan, L., & Meigs, J. B. (2005). Metabolic syndrome as a precursor of cardiovascular disease and type 2 diabetes mellitus. Circulation, 112(20), 3066–3072. doi:10.1161/CIRCULATIONAHA.105.539528

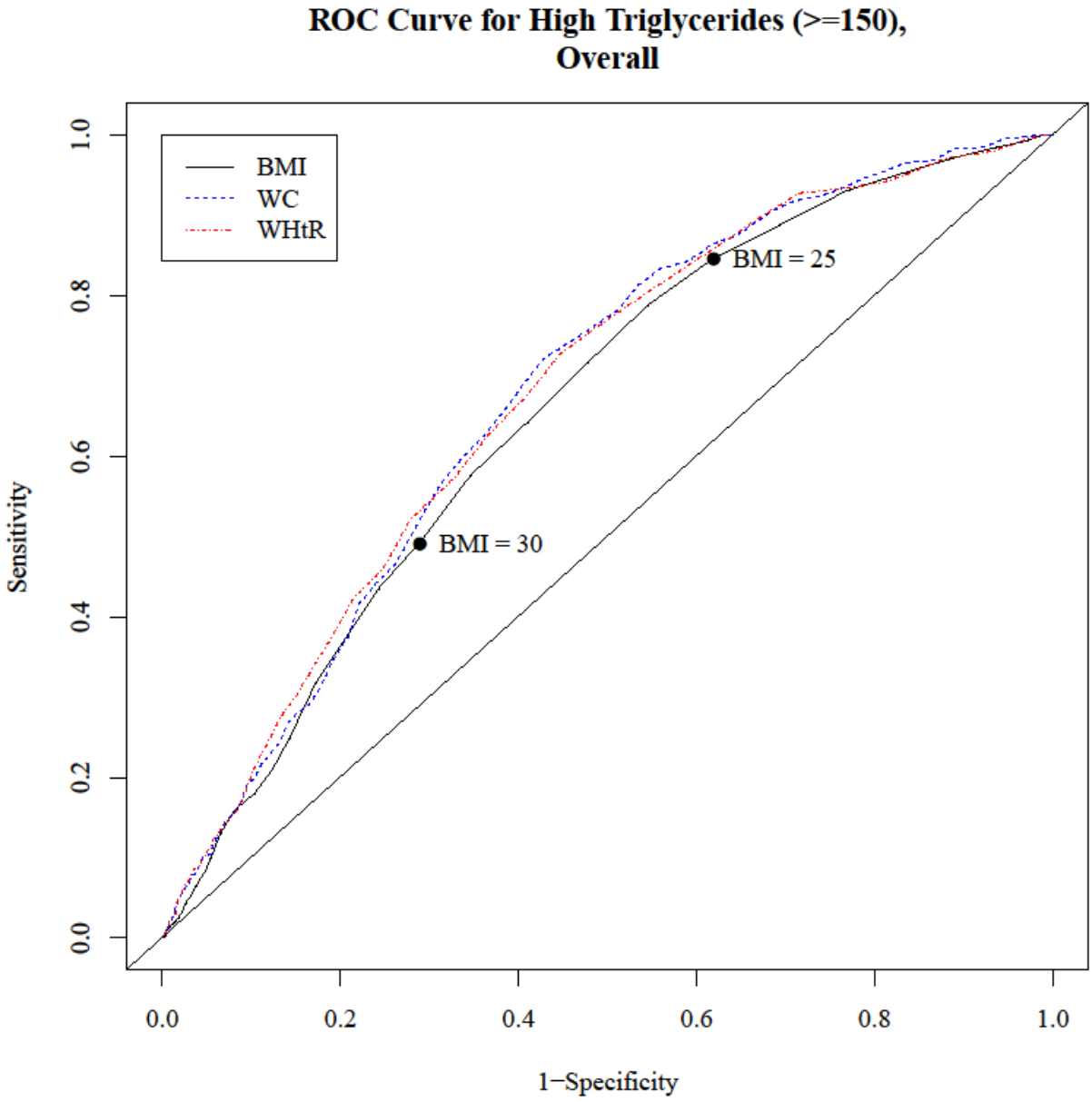
Wolter, K. (2007). Introduction to Variance Estimation. Springer.

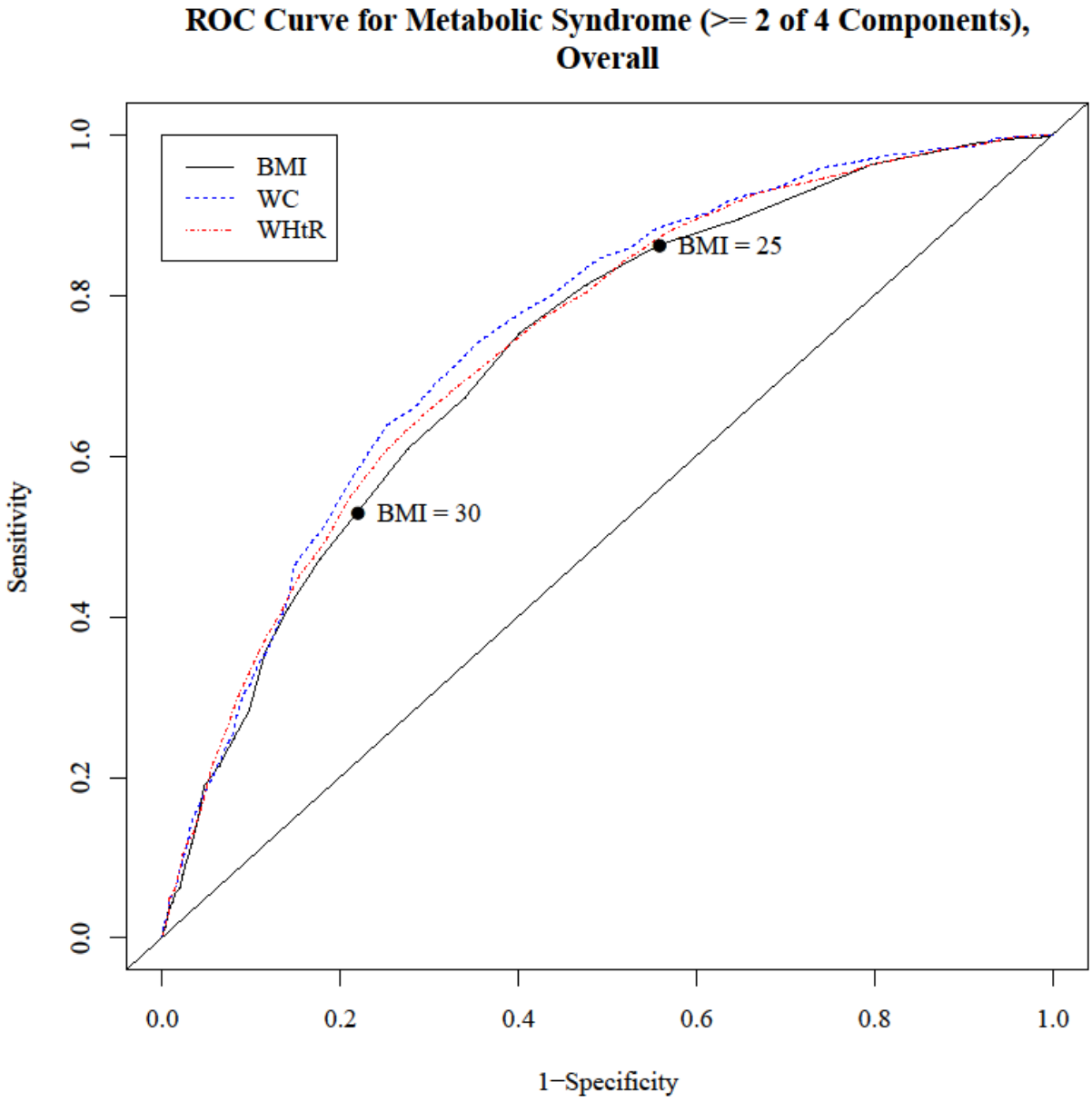
**Appendix – ROC Curve**

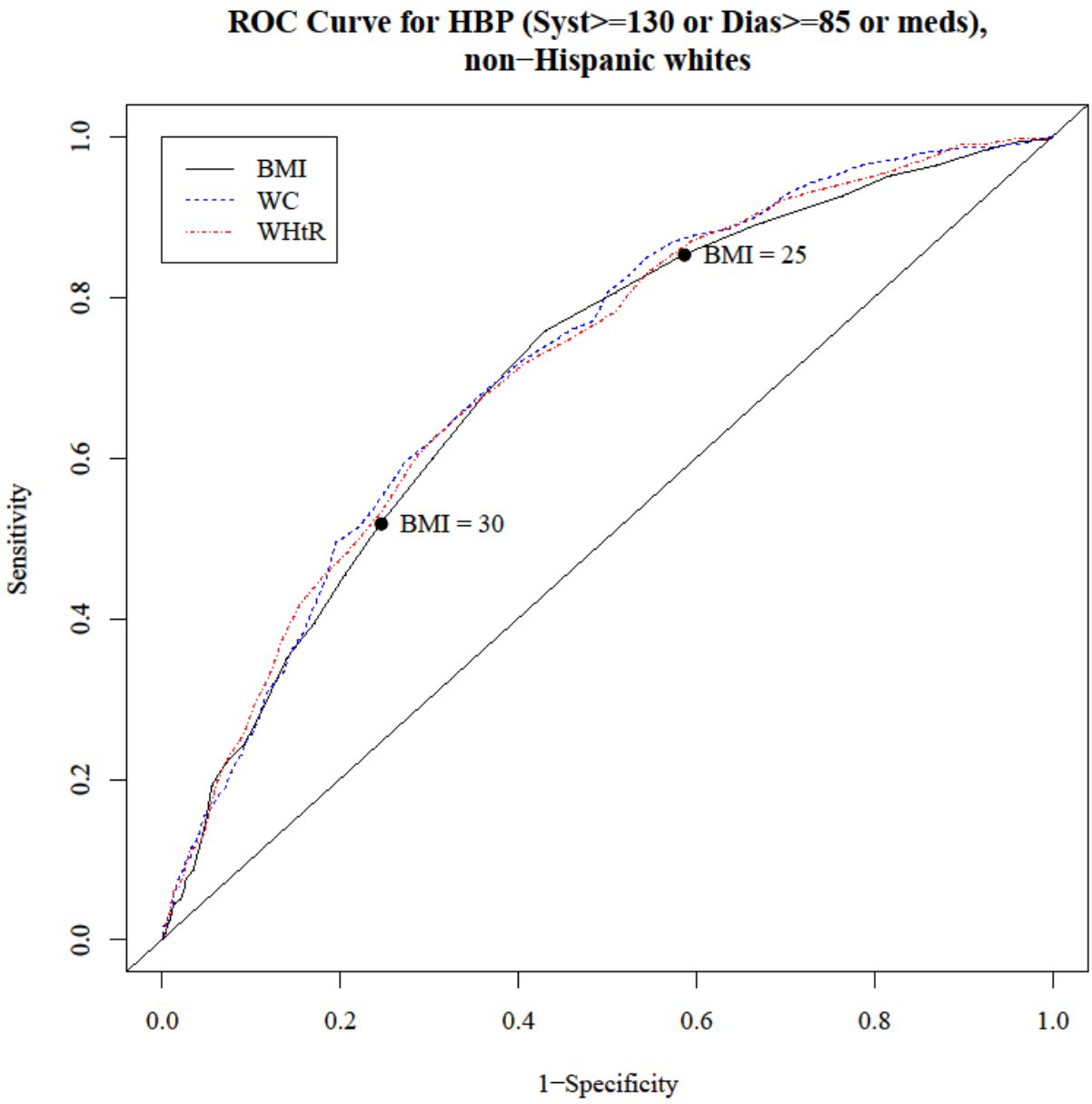


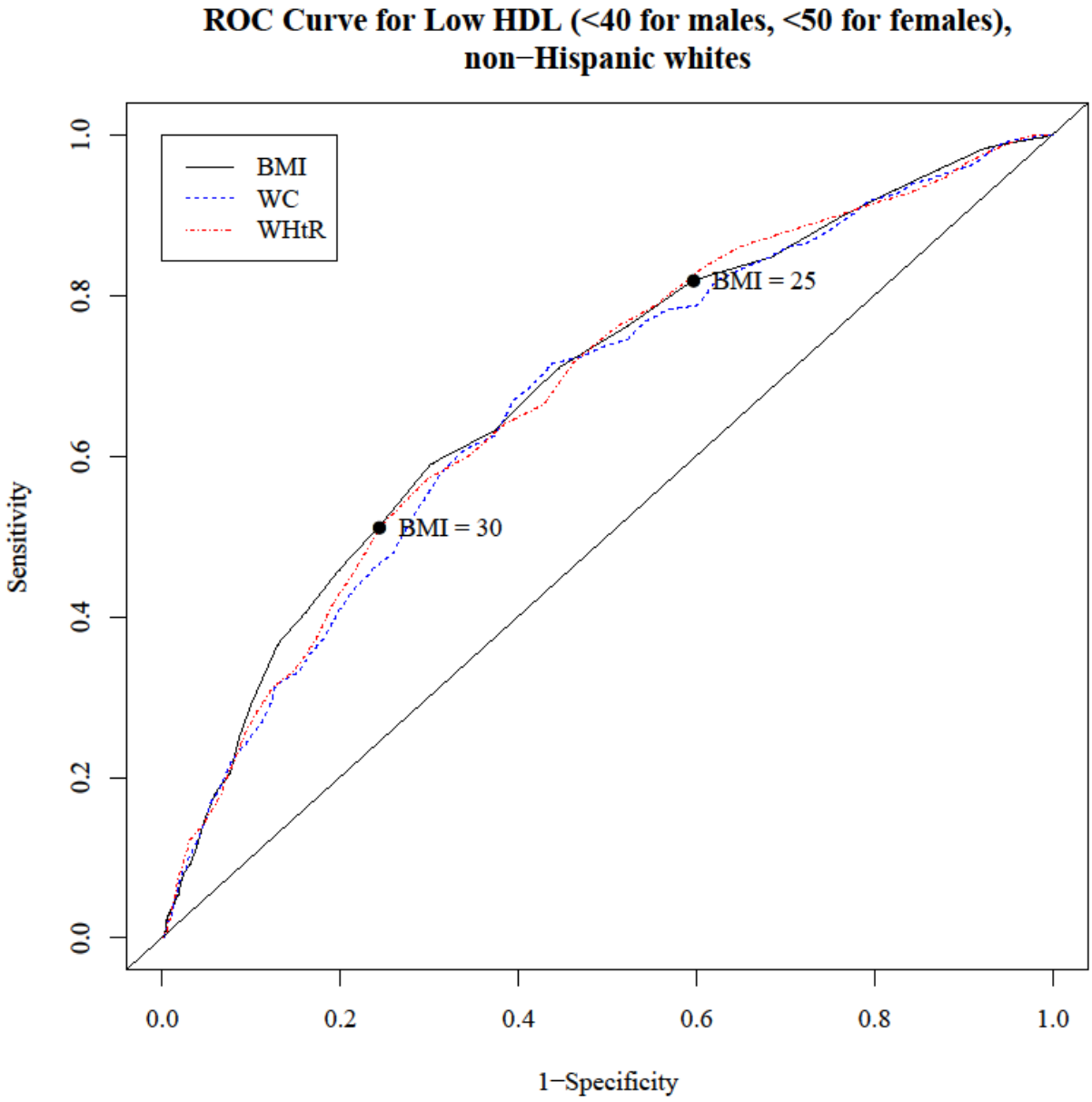

ROC Curve for Low HDL (<40 for males, <50 for females), Overall
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0

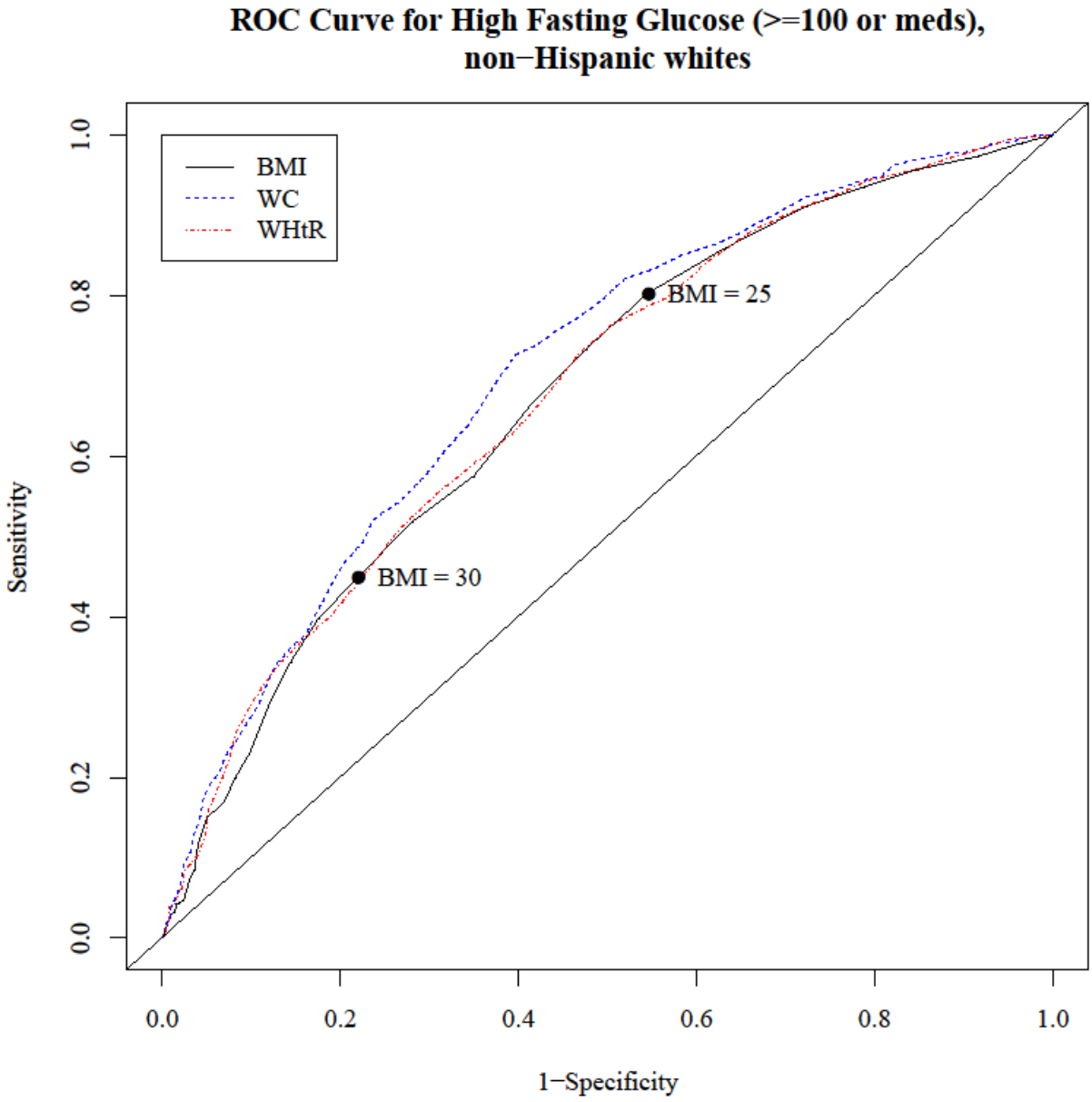

ROC Curve for High Fasting Glucose (>=100 or meds), Overall
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0

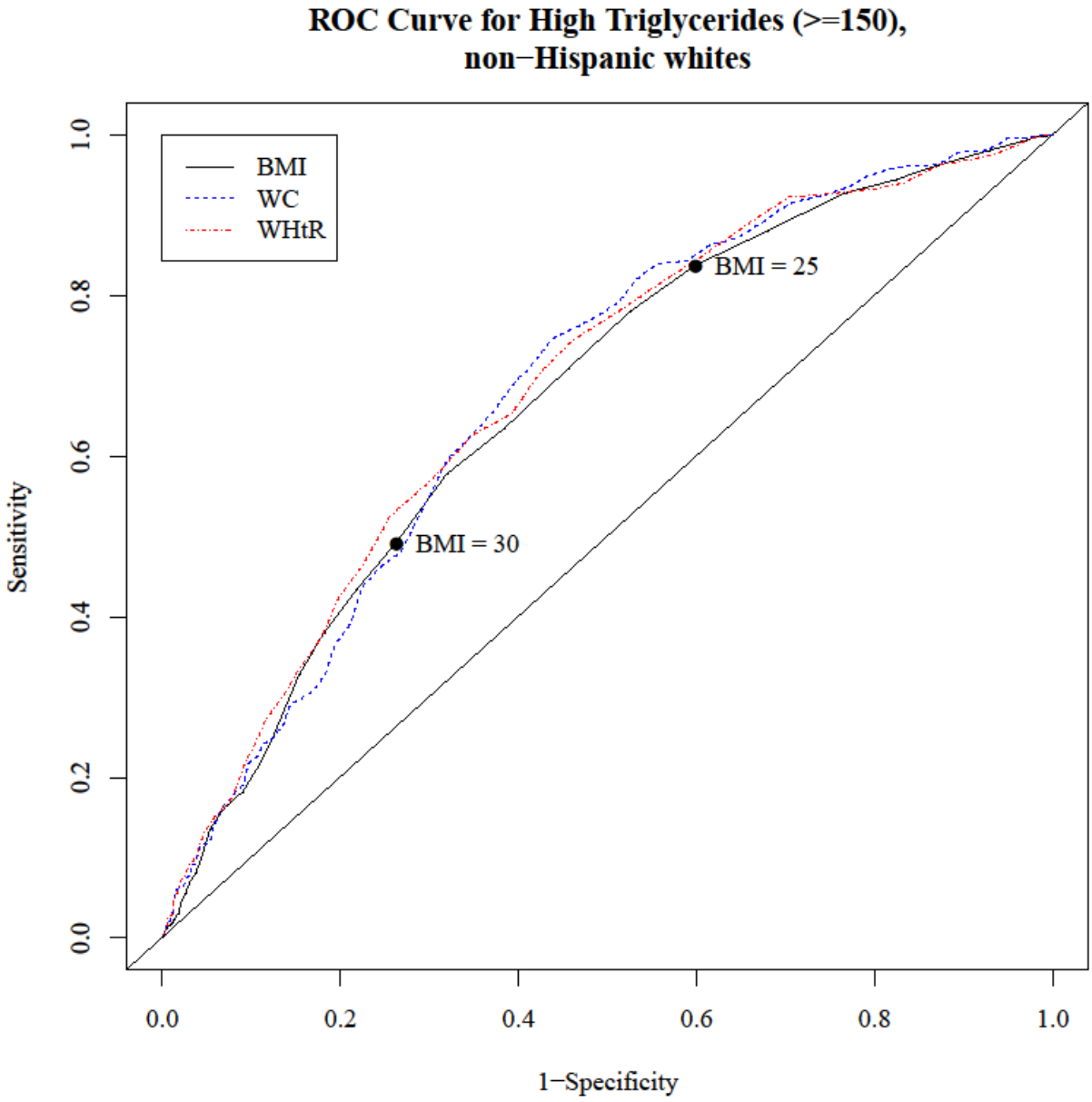

ROC Curve for High Triglycerides (>=150),
Overall
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0

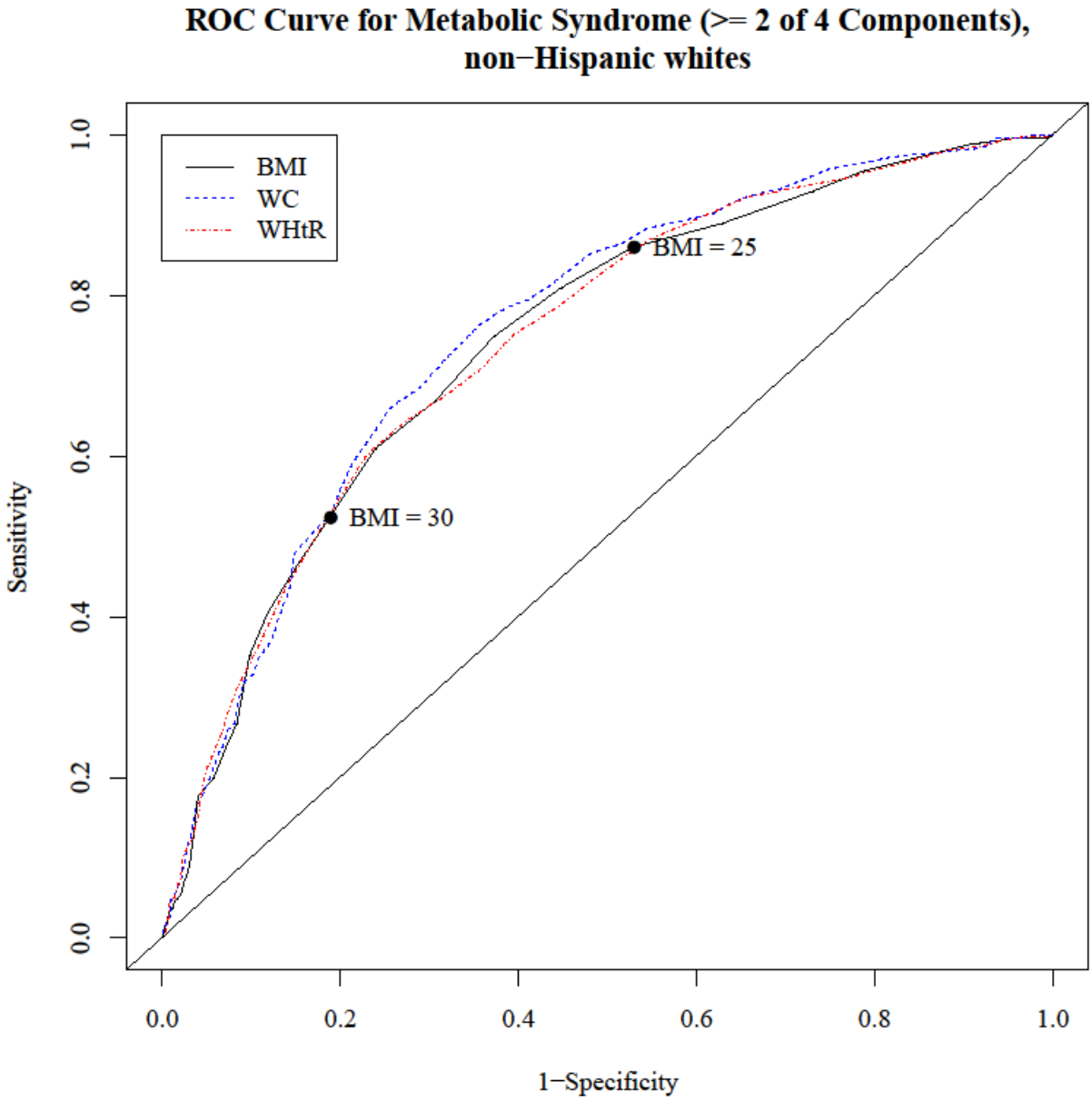

ROC Curve for Metabolic Syndrome (>= 2 of 4 Components), Overall
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0

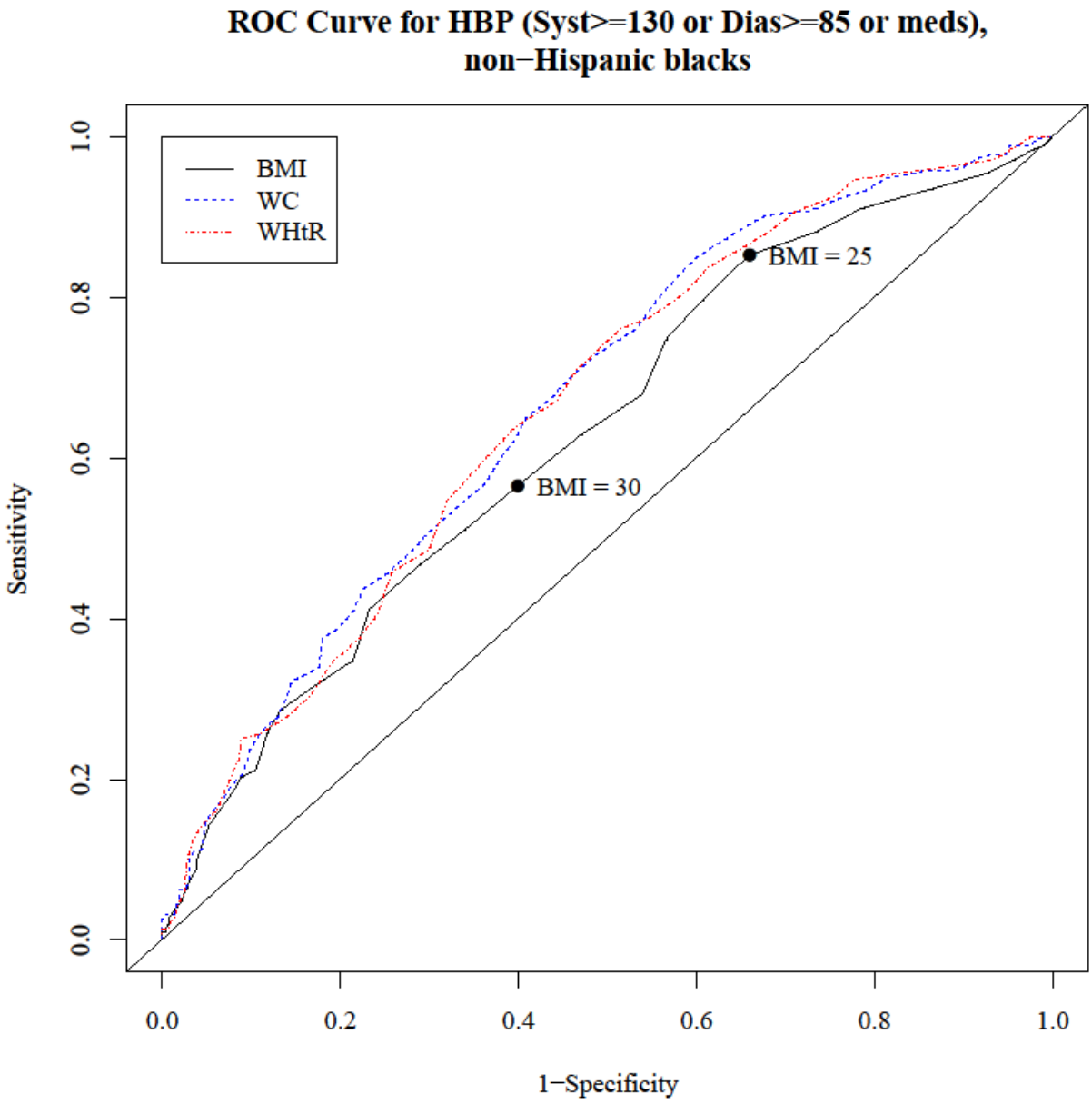

ROC Curve for HBP (Syst>=130 or Dias>=85 or meds),
non−Hispanic whites
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0

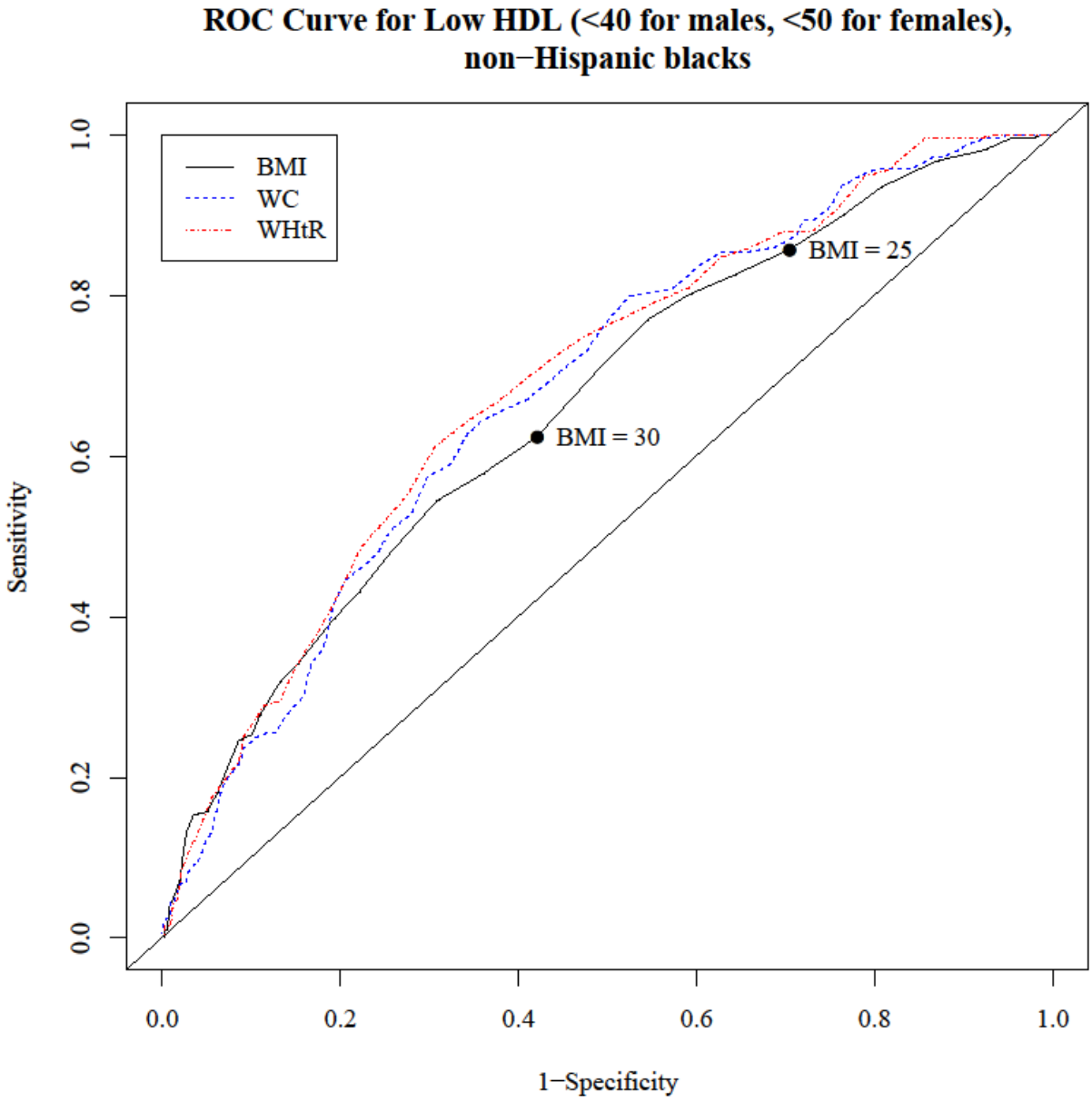

ROC Curve for Low HDL (<40 for males, <50 for females), non−Hispanic whites
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0

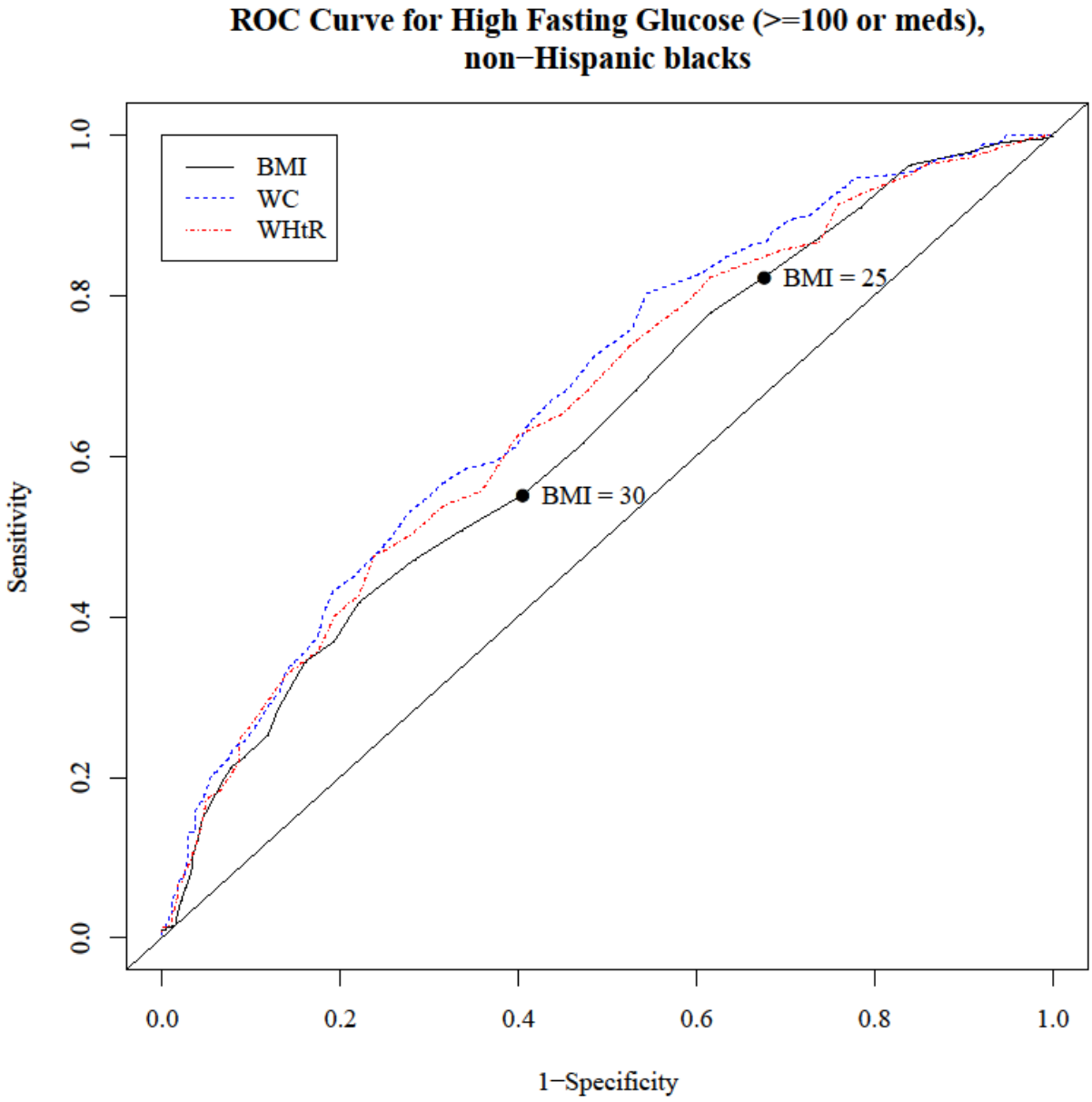

ROC Curve for High Fasting Glucose (>=100 or meds),
non−Hispanic whites
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0

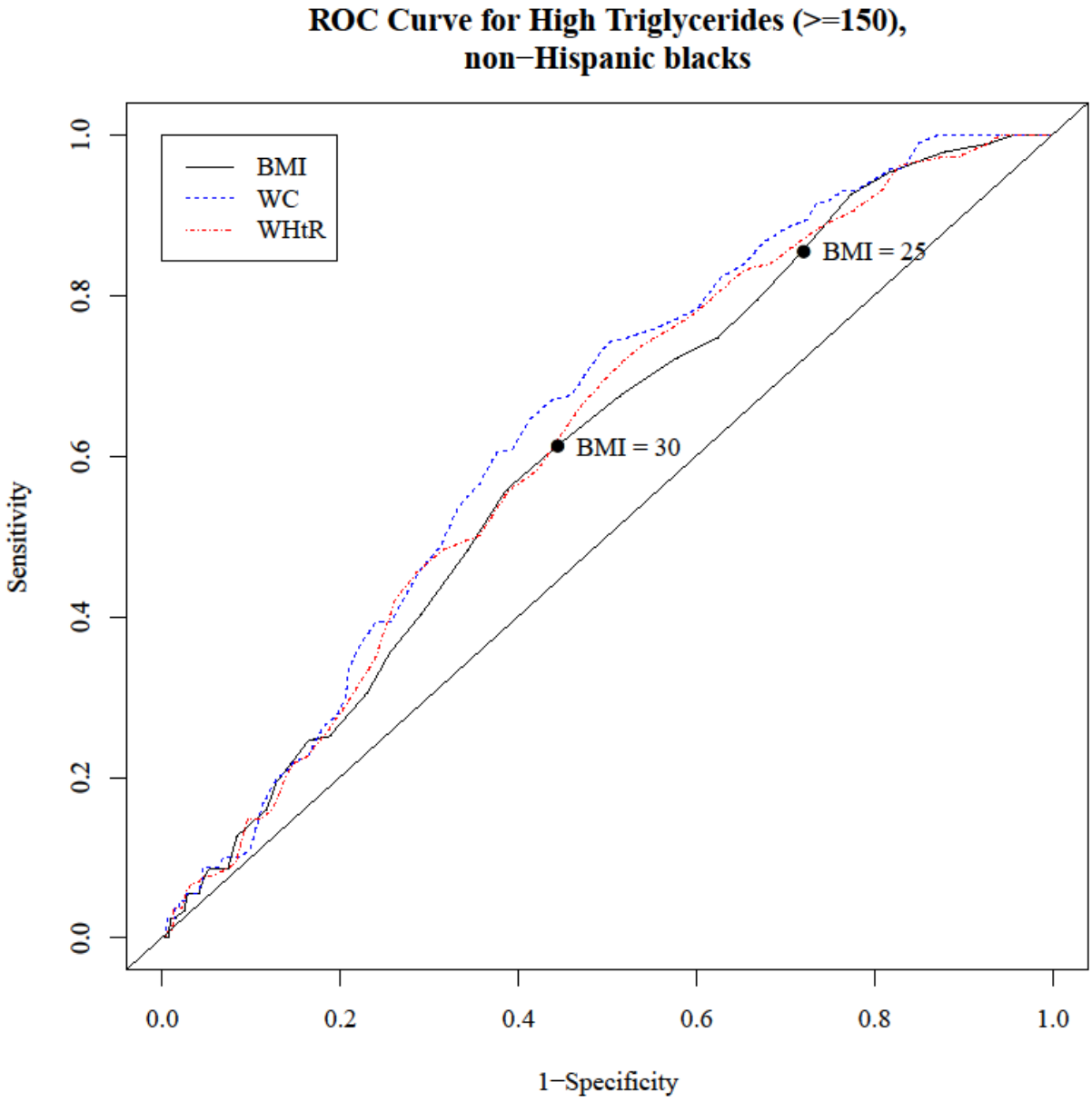

ROC Curve for High Triglycerides (>=150),
non−Hispanic whites
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0

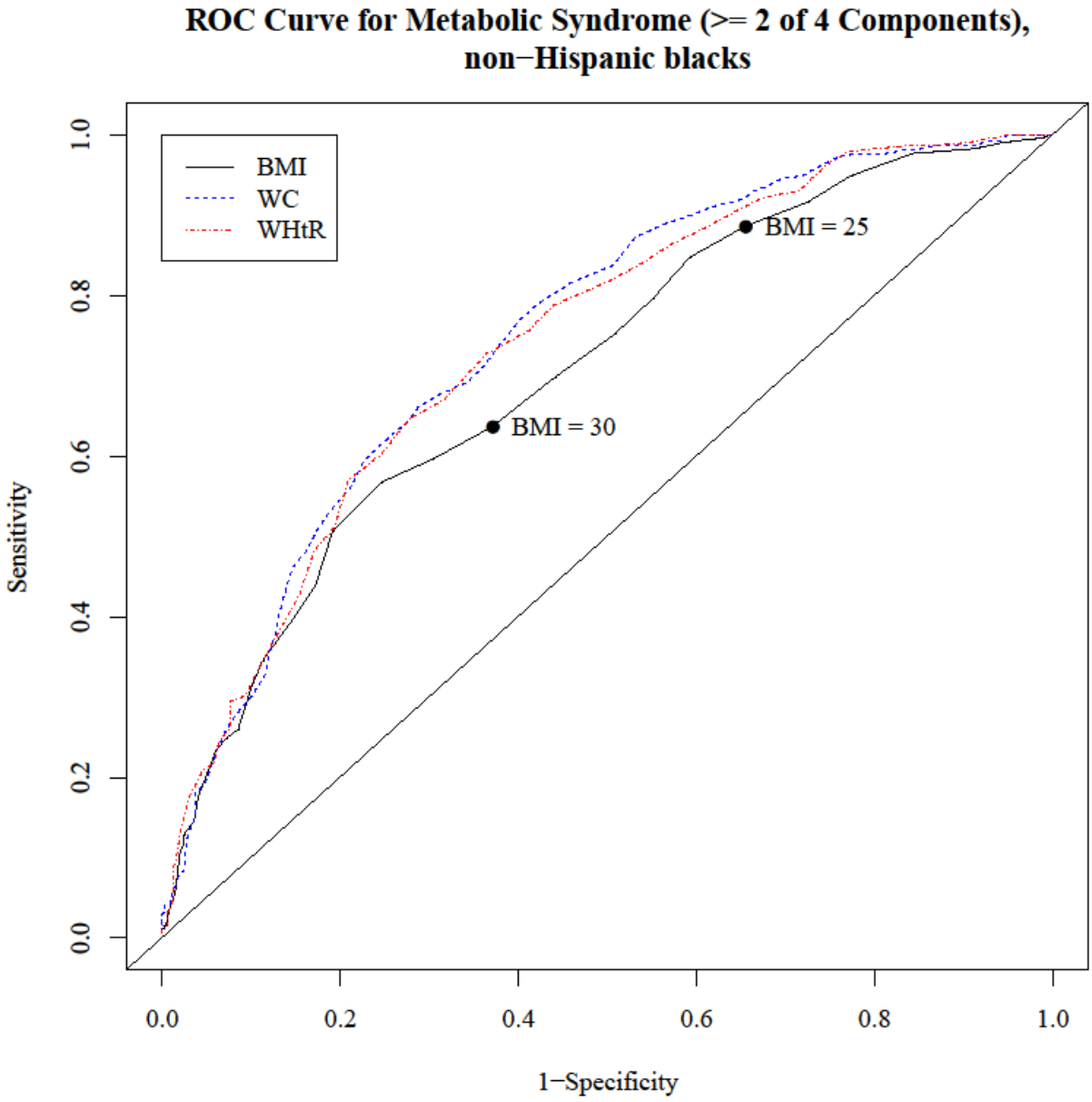

ROC Curve for Metabolic Syndrome (>= 2 of 4 Components), non−Hispanic whites
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0

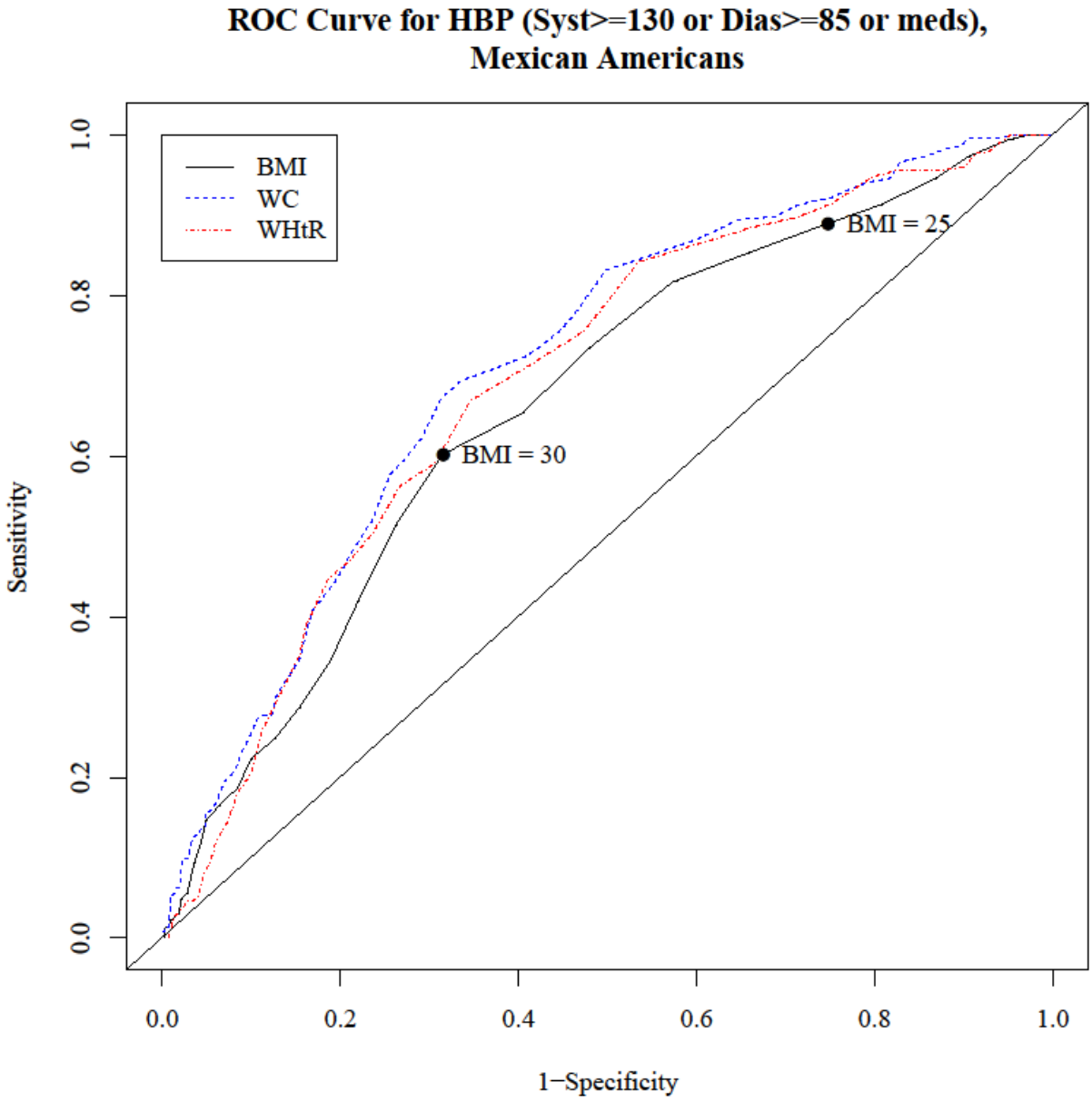

ROC Curve for HBP (Syst>=130 or Dias>=85 or meds),
non−Hispanic blacks
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0

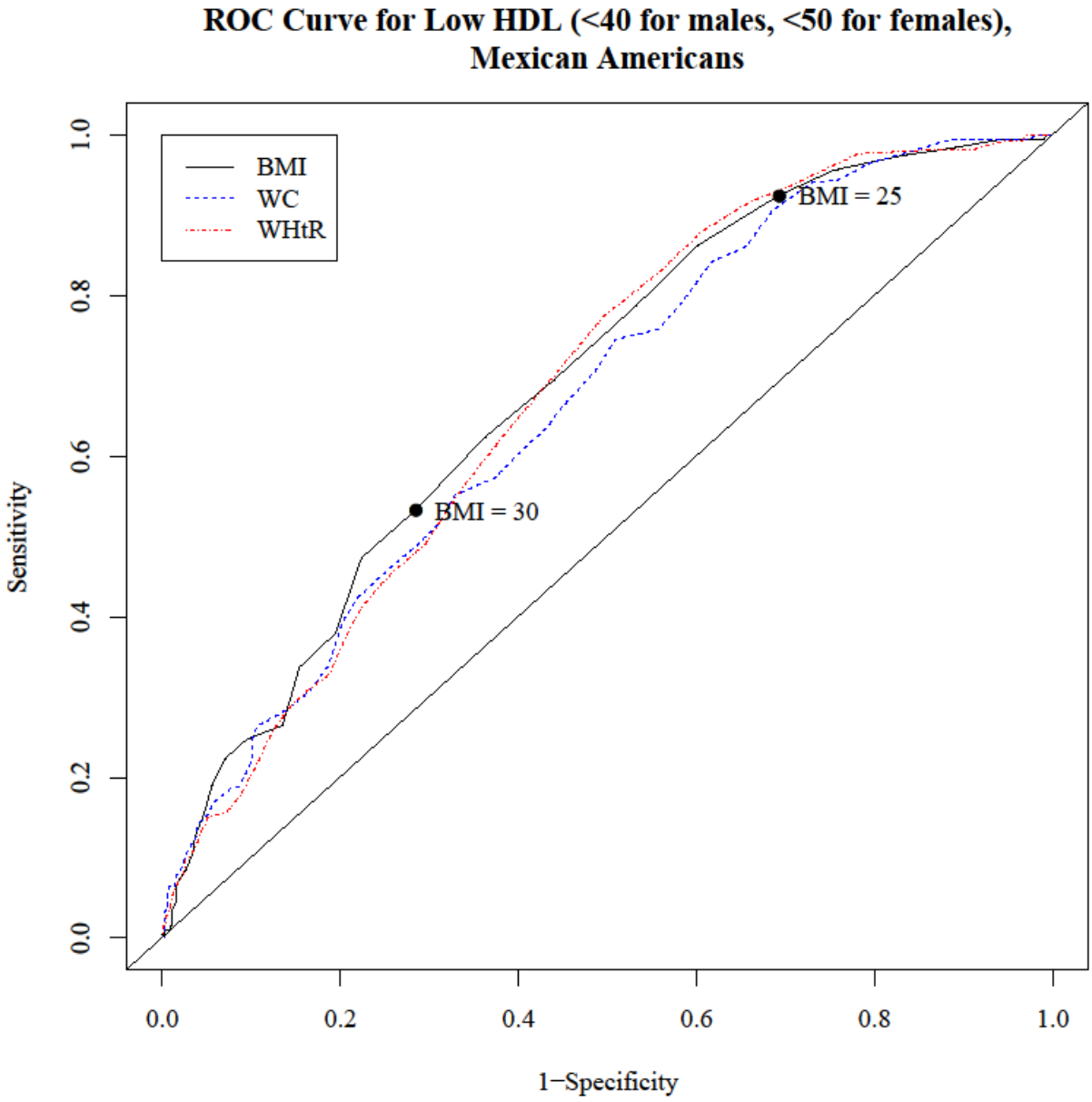

ROC Curve for Low HDL (<40 for males, <50 for females),
non−Hispanic blacks
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0

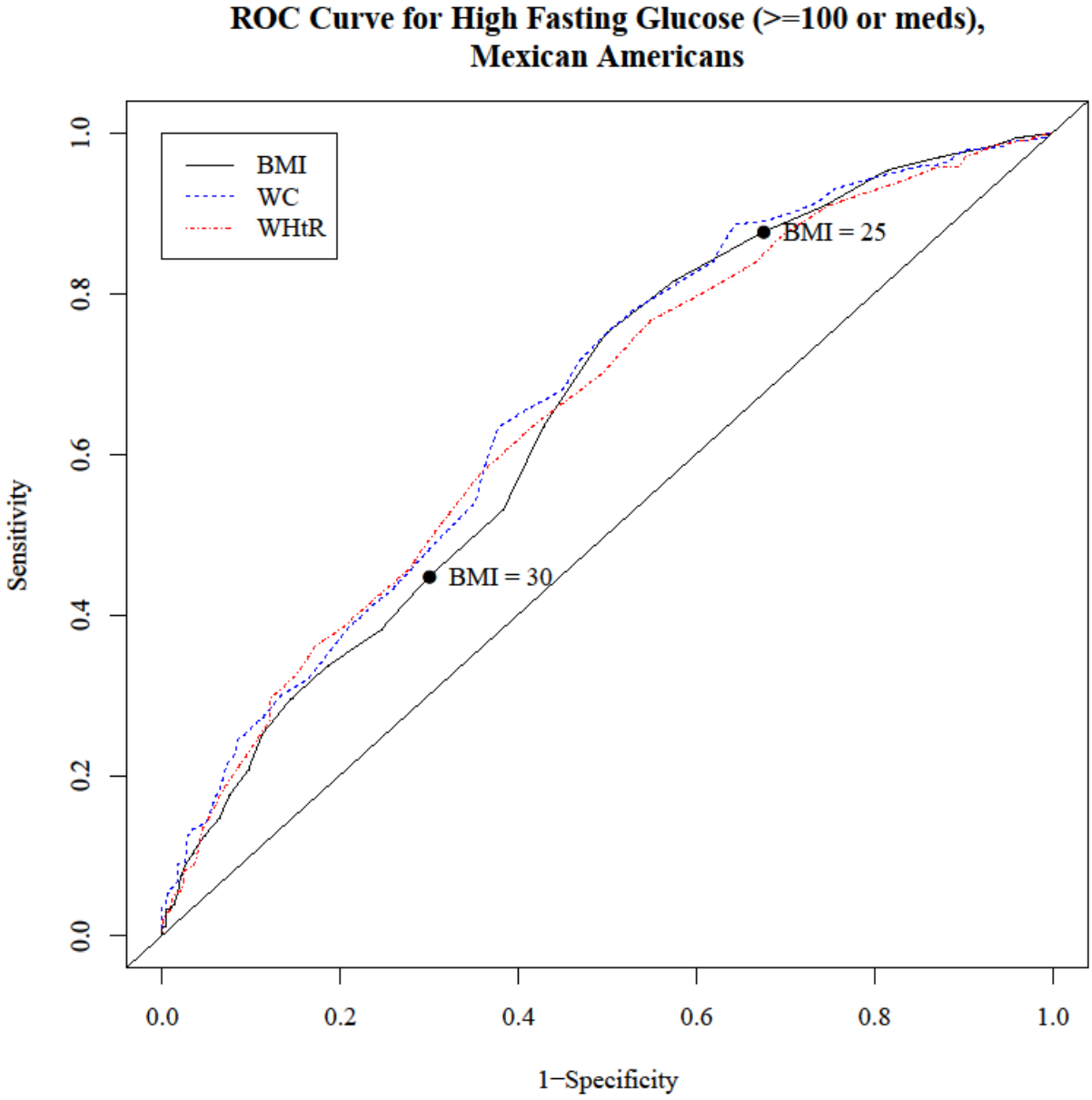

ROC Curve for High Fasting Glucose (>=100 or meds),
non−Hispanic blacks
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0

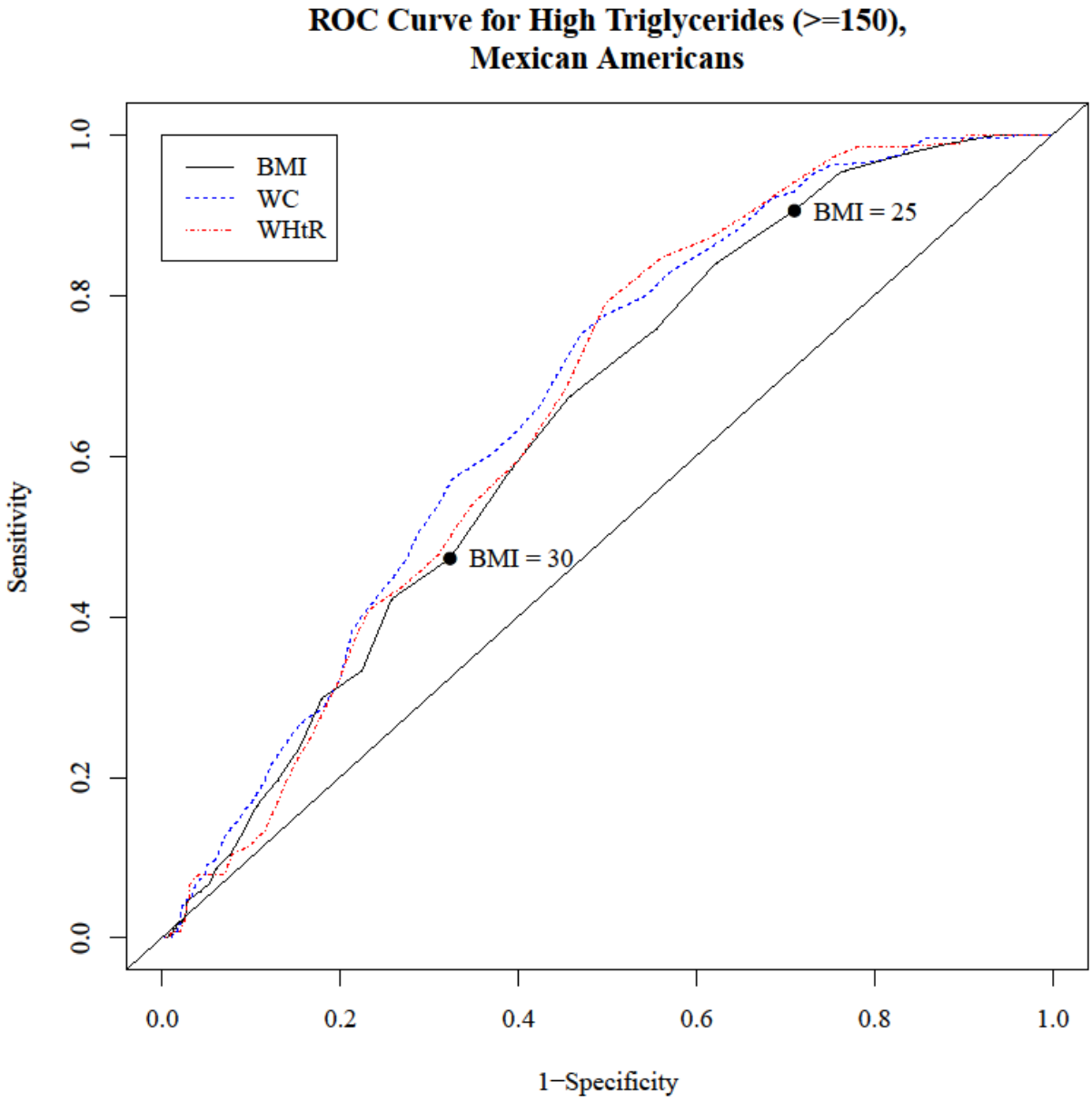

ROC Curve for High Triglycerides (>=150),
non−Hispanic blacks
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0

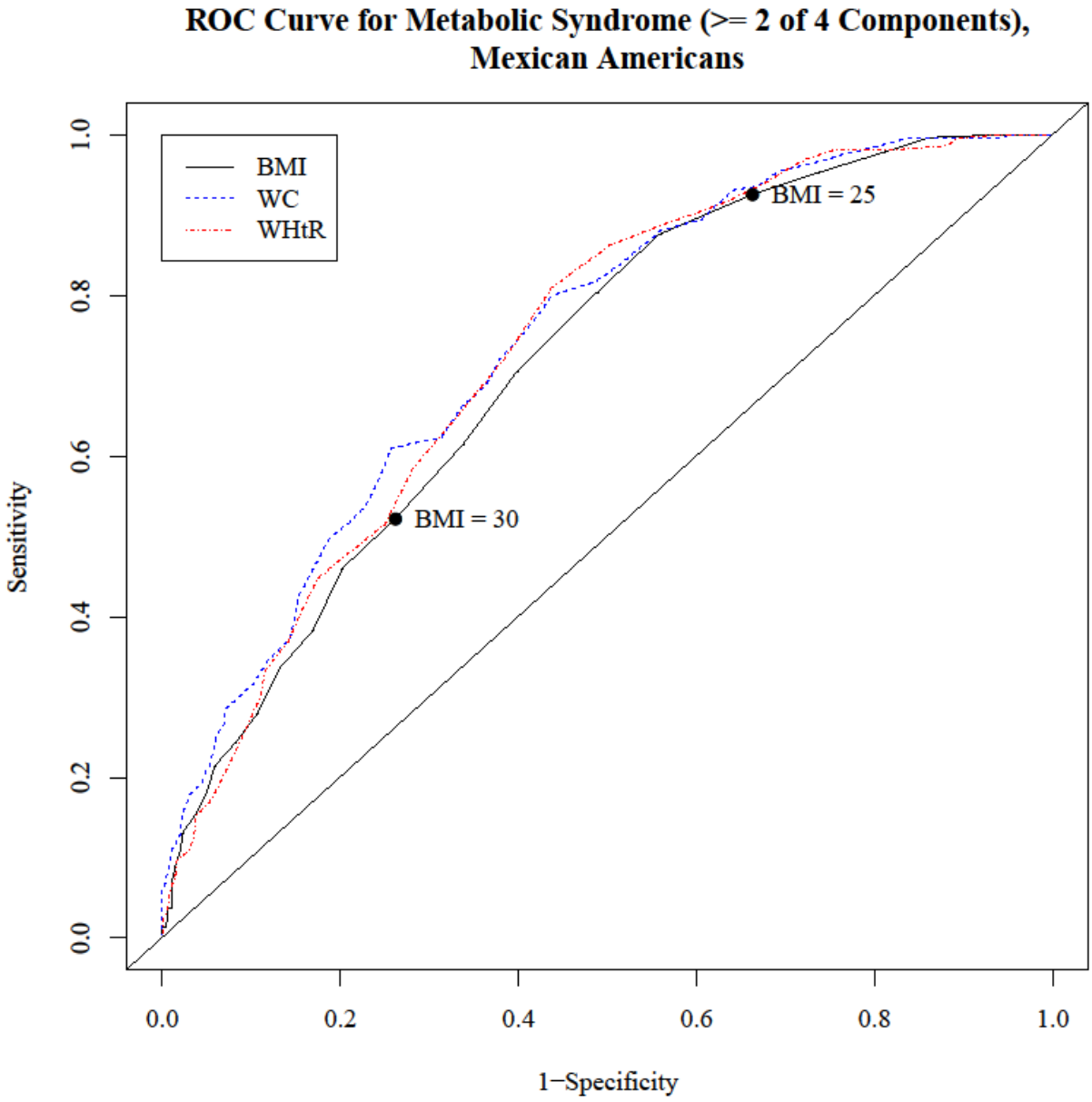

ROC Curve for Metabolic Syndrome (>= 2 of 4 Components),
non−Hispanic blacks
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0


ROC Curve for HBP (Syst>=130 or Dias>=85 or meds),
Mexican Americans
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0


ROC Curve for Low HDL (<40 for males, <50 for females), Mexican Americans
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0


ROC Curve for High Fasting Glucose (>=100 or meds),
Mexican Americans
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0


ROC Curve for High Triglycerides (>=150),
Mexican Americans
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0


ROC Curve for Metabolic Syndrome (>= 2 of 4 Components), Mexican Americans
BMI
WC
WHtR
BMI = 25
BMI = 30
Sensitivity
1−Specificity
0.0
0.2
0.4
0.6
0.8
1.0