Preventive Medicine 88 (2016) 1–7

Contents lists available at ScienceDirect

Preventive Medicine

journal homepage: www.elsevier.com/locate/ypmed

Differential association of cardiorespiratory fitness and central adiposity among US adolescents and adults: A quantile regression approach

Samantha M. McDonald [a,*], Andrew Ortaglia [b], Matteo Bottai [c], Christina Supino [d]

[a] Department of Exercise Science, Arnold School of Public Health, University of South Carolina, Columbia, SC, United States
[b] Department of Epidemiology and Biostatistics, Arnold School of Public Health, University of South Carolina, Columbia, SC, United States
[c] Division of Biostatistics, Institute of Environmental Medicine, Karolinska Institutet, Stockholm, Sweden
[d] Department of Premedical Studies, University of Vermont, Burlington, VT, United States

ARTICLE INFO

Article history:
Received 22 September 2015
Received in revised form 7 March 2016
Accepted 17 March 2016
Available online 19 March 2016

Keywords:
Aerobic capacity
Cardiorespiratory
Waist circumference
Quantile regression

ABSTRACT

Previous studies assessing the association between cardiorespiratory fitness (CRF) and waist circumference (WC) have often restricted their evaluation to the association of CRF on average WC. Consequently, the assessment of important variations in the relationship of CRF across the WC distribution was precluded. The purpose of this study was to comprehensively evaluate the association between CRF and the distribution of WC using quantile regression. Secondary data analysis was conducted using data from the 1999–2004 NHANES. Participants (n = 8260) aged 12–49 years with complete data on estimated maximal oxygen consumption and WC were included. Quantile regression models were performed to assess the association between CRF and the 10th, 25th, 50th, 75th and 90th WC percentiles and were adjusted for age and race/ethnicity. For male and female adolescents with high CRF compared to low-fit counterparts, significant negative estimates (2.8 to 20.2 cm and 2.3 to 11.2 cm, respectively) were observed across most WC percentiles. Similarly, among male and female adults, high CRF was associated with significant reductions in WC across all percentiles (9.5 to 12.0 cm and 3.7 to 9.2 cm, respectively). For both populations, an increasing trend in the magnitude of the association of high CRF across the WC percentiles was observed. CRF appears to have a differential relationship across the WC distribution with the largest reductions in WC were found among high-fit individuals with the greatest amount of central adiposity (WC ≥ 90th percentile). Additionally, this differential association highlights the significant limitations of statistical techniques used in previous analyses which focused on the center of the distribution.

1. Introduction

Recent epidemiological evidence suggests that the mean waist circumference (WC) in the US population, a measure of central adiposity, has increased roughly two centimeters in adult men and four centimeters in adult women over the past decade (Freedman & Ford, 2015). Similarly, the prevalence of abdominal obesity (WC ≥ 90th percentile; NHANES 1988–2012) rose between 62% and 162% among adolescents (aged 12 to 19 years) in the past two decades, leveling off near 22% in 2011–2012 (Li et al., 2006; Xi et al., 2014). Importantly, augmented levels of central adiposity, a surrogate marker of visceral adipose tissue deposition, have been shown to be positively associated with risks of non-communicable diseases (e.g. cardiovascular disease (Nakamura et al., 1994)) and their risk factors (e.g. hypertension (Cox et al., 1998), hyperglycemia (Pouliot et al., 1992)) among adults and adolescents. The potentially severe health ramifications associated with central adiposity have prompted extensive research to be conducted in an effort to identify factors related to elevated levels of abdominal adiposity.

Evidence indicates that cardiorespiratory fitness (CRF), defined as the "*ability to engage in physical activities that rely on oxygen consumption as the primary source of energy…and the body's ability to transport and utilize oxygen*" (Swain & Brawner, 2014) is inversely associated with central adiposity, which has been consistently demonstrated among both youth and adult populations (Brunet et al., 2006; Ross & Katzmarzyk, 2003). Because CRF is a(n) state or attribute of an individual, the physiological mechanisms that underlie its relationship with central adiposity are likely reflective of the cardiovascular (Convertino, 1991), musculoskeletal (Harms & Hickson, 1983) and metabolic adaptations (Shojaee-Moradie et al., 2007) that occur with chronic high-intensity exercise training (Wenger & Bell, 1986). While considerable evidence exists to support the inverse relationship between CRF and central adiposity (Eteng et al., 2010; Ross & Katzmarzyk, 2003), previous analyses have largely been restricted to assessments of the potential impact of CRF on average central adiposity. Considering the average of central adiposity alone, previous analyses did not assess important variations in the impact of CRF across the WC distribution among adolescents and adults.

* Corresponding author at: Public Health Research Center, Children's Physical Activity Research Group, 921 Assembly Street, Suite 212, Columbia, SC 29208, United States.
E-mail address: mcdona84@email.sc.edu (S.M. McDonald).

http://dx.doi.org/10.1016/j.ypmed.2016.03.014
0091-7435/

Additionally, previous studies examining the association between CRF and adiposity have been conducted in relatively small samples, with younger populations, and in non-racially/ethnically diverse samples. Considering the racial/ethnic differences in the distribution of adipose tissue deposition in adolescent and adult populations (Carroll et al., 2008; Després et al., 2000), it is plausible that the influence of CRF on central adiposity may differ across various racial/ethnic (Camhi et al., 2011), age and sex groups (Enzi et al., 1986). Collectively, the preponderant use of linear regression methods to quantify the association between CRF and central adiposity mostly among small and/or non-racially/ethnically diverse samples has potentially resulted in an incomplete evaluation of this clinically important relationship.

In order to expand upon the existing evidence, a comprehensive evaluation of the association between CRF and central adiposity is necessary. Quantile regression is a semi-parametric statistical method (Koenker, 2005) that enables the association of CRF to be estimated across several percentiles of central adiposity. As a result, potential variations in the magnitude of CRF across differing levels of central adiposity can be quantified. Despite its numerous advantages (e.g., no distributional assumptions), this method has been used sparingly in the public health field (Bottai et al., 2014), and to our knowledge has never been used to evaluate the relationship between CRF and central adiposity. Thus, the purpose of this study is to comprehensively evaluate the association between CRF and the entire distribution of central adiposity in a large, diverse, nationally representative sample of adolescents and adults.

2. Methods

2.1. Survey design and study population

This study employed a secondary analysis of data from the 1999–2004 cycles of The National Health and Nutrition Examination Survey (NHANES), a series of cross-sectional population-level surveys from a nationally representative sample of non-institutionalized US residents (Johnson et al., 2013). For the purpose of this study, only participants aged 12 to 49 years will be included in the analyses as the cardiovascular fitness test, a component of the physical examination, was restricted to those within this age range.

As part of the physical examination, 14,417 participants aged 12 to 49 years were randomly selected to participate in the cardiovascular fitness test. Of these participants, 2626 met the exclusion criteria which consisted of the presence of physical limitations, cardiovascular and/or respiratory conditions, asthma symptoms or specified medications. In addition, women that were >12 weeks pregnant were also excluded from the fitness test ($n = 698$). Of the remaining 11,093 eligible participants, 2769 did not complete the test for various reasons (e.g. refusal, technical issue) (Centers for Disease Control and Prevention & NHANES Cardiovascular Fitness Procedures Manual. Centers for Disease Control and Prevention, National Center for Health Statistics, 2005), resulting in 8324 completing the cardiovascular fitness test and maximal oxygen consumption estimated.

2.2. Maximal oxygen consumption

Maximal oxygen consumption (VO_{2max}) was estimated via a submaximal exercise test performed on a treadmill. The treadmill exercise test consisted of a 4-stage protocol which included a two-minute warm-up stage, two three-minute exercise stages and a two-minute cool-down stage (Centers for Disease Control and Prevention & NHANES Cardiovascular Fitness Procedures Manual. Centers for Disease Control and Prevention, National Center for Health Statistics, 2005). Heart rate (HR) and blood pressure were continuously monitored and recorded throughout all stages of the exercise test and VO_{2max} was estimated by linear extrapolation (Centers for Disease Control and Prevention & NHANES Cardiovascular Fitness Procedures Manual. Centers for Disease Control and Prevention, National Center for Health Statistics, 2005). VO_{2max} was expressed relative to the participants' weight as milliliters of oxygen per kilogram of body weight per minute (mL $O_2 \cdot kg^{-1}\ min^{-1}$).

2.3. Level of cardiorespiratory fitness

The estimated VO_{2max} calculated from the submaximal exercise test was categorized into three levels of CRF (high, moderate and low) using age- and sex-specific cut-points. For adults (aged 20 to 49 years), the cut-points were based on the Aerobics Center Longitudinal Study population, (Blair et al., 1989) where low, moderate and high levels of fitness were defined as an estimated VO_{2max} <20th percentile, 20th to 59th percentile and ≥60th percentile, respectively. The levels of fitness for adolescents and young adults (aged 12 to 19 years) were categorized similarly, however the estimated VO_{2max} values used to determine the cut-points were based on the criteria from the FITNESSGRAM (Cureton & Warren, 1990).

2.4. Central adiposity — waist circumference

Central adiposity was assessed by measuring the waist circumference (WC) of the participants via a measuring tape per the NHANES anthropometric manual (Centers for Disease Control and Prevention & National Health and Nutrition Examination Survey (NHANES): Anthropometry Procedures Manual, 2004) and was recorded to the nearest millimeter.

2.5. Covariates

Covariates with an established physiological relationship with CRF and central adiposity were considered in our analyses and included age (in years) (Sowers et al., 2007) and race/ethnicity (Carroll et al., 2008). Race/ethnicity was categorized into the following four groups: Non-Hispanic White, Non-Hispanic Black, Mexican American, Hispanic and Other.

2.6. Statistical analysis

All statistical analyses including descriptive statistics (frequencies, means, and standard deviations) and regression models were stratified into the following four age by sex categories; males 12–19 years, females 12–19 years, males 20–49 years and females 20–49 years of age. Quantile regression was used to assess the associations between CRF and WC at the10th, 25th, 50th, 75th, and 90th WC percentiles. The statistical software "R" version 3.12 was used for all analyses with the survey package being extended to accommodate quantile regression and account for the complex NHANES survey design with standard errors being calculated using replicate weights (Lumley, 2010). Quantile regression coefficients are interpreted similarly to those of ordinary linear regression coefficients except that a quantile regression coefficient indicates the change in the value at the modeled percentile, not the mean, of the dependent variable. For example, consider the categorical predictor CRF status with three levels; high, moderate and low (referent level). A coefficient estimate of −10 for high fitness in the quantile regression model for the 90th percentile would indicate that the 90th percentile of WC is estimated to be 10 cm less for people of a high fitness level as compared to those with a low fitness level after controlling for other covariates in the model.

For the quantile regression analyses WC (cm) was treated as the dependent variable. CRF, age and race/ethnicity were included as independent variables in the regression models. In the analyses for both males and females aged 20–49 a linear spline with a knot at 40 years was included to account for a potential change in either the magnitude or the direction of the association between WC and age as adults reach middle age (Stevens et al., 2009).