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Cardiorespiratory Fitness and Leg Muscle Power in Relation to Abdominal Adipose Tissue in Adolescents

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ABSTRACT

Background: Abdominal adiposity is associated with high risk of cardiometabolic diseases. Waist circumference has been used as a surrogate measure of abdominal adipose tissue in both youth and adults. **Objectives:** The present study evaluated whether cardiorespiratory fitness and leg power (LP) were independently associated with abdominal adipose tissue in 12-16-year-old Nigerian adolescents. **Methods:** This cross-sectional study comprised 2047 (1087 girls and 960 boys) adolescents who were evaluated for cardiorespiratory fitness and leg power. The cardiorespiratory fitness and leg power were assessed using the progressive cardiovascular endurance run (PACER) test and the vertical jump (VJ) test, respectively. Abdominal adiposity was evaluated with the waist circumference (WC). Regression models controlling for age and maturity status were used to assess the association of fitness and LP with WC. **Results:** Low leg power had significant negative association with the risk of abdominal adiposity in both girls (β=-0.307; p<0.001) and boys (β=-0.262; p<0.001). The observed relationship was independent of fitness, whereas the relationship between fitness and risk of abdominal adiposity was partly determined by leg power. **Conclusion:** Leg power and fitness were independently associated with the risk of abdominal adiposity in adolescents, but the association of leg power was stronger in girls. Health promotion efforts targeting reduction of abdominal adipose tissue should also include muscular power training type activities in addition to endurance-related activities.

Key words: Adolescent, Abdominal, Cardiorespiratory Fitness, Vertical Jump, Gender Differences, Obesity

INTRODUCTION

Obesity is a health problem globally due to its high spread and strong association with a range of health problems like hypertension, diabetes mellitus, metabolic syndrome and dyslipidemia (Musa & Dominic, 2021, Musa et al. 2021, Reiner, 2013). Childhood obesity has attained epidemic proportions and is a precursor of adult obesity (WHO 2000, Niclasen, Petzold & Schnor, 2007). Given the substantial upsurge in the incidence of obesity and overweight in many developing countries (Musa, Angba & Bamidele, 2019; Monyeki et al., 2017), with childhood obesity as a precursor of adult obesity (Niclassen et al., 2007), it is imperative to identify children at risk of this disease to facilitate early intervention aimed at minimizing its progression.

Although obesity is commonly associated with many cardiometabolic diseases like hypertension and diabetes (Oduwole et al., 2012), research has reported localized adipose tissue or its distribution, particularly an android fat pattern with excessive fat around the abdomen to be more closely associated with these diseases than obesity itself (Ben Mohammed et al., 2011; Buchan et al., 2013). These findings have renewed the scientific community's interest in studying body fat distribution and its relative effect on health, especially among the youth (Lee & Arslanian, 2007; Kelishadi et al., 2015).

The waist circumference (WC), a proxy measure of abdominal fat distribution (Maffies, 2000) is a component of metabolic syndrome, the coexistence of many cardiovascular disease risk factors in an individual which is linked to type 2 diabetes mellitus, coronary heart disease, and some types of cancer (Kelishadi et al., 2015). Although abdominal fat is considered a chronic disease risk, visceral adipose tissue (VAT)

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(intrabdominal fat depot) is strongly associated with metabolic abnormalities than subcutaneous adipose tissue (SAT) (present under the skin and abdominal area) (An et al., 2019; Ibrahim, 2010). Like in many chronic diseases, abdominal adiposity manifests mainly during adulthood. However, its metabolic perturbations begin in childhood (Misra & Vikram, 2003).

Several studies in adolescents have documented negative relationships between adiposity and cardiorespiratory fitness (CRF) (Musa et al., 2019; Bonney et al., 2018; Gonzalez-Sarez et al., 2013). Among the health-related physical fitness components, CRF in relation to cardiometabolic risk or individual components of metabolic syndrome has been most frequently studied compared to other components of physical fitness (Lee & Arslanian, 2007; Bonney et al., 2018). Previous research has demonstrated the association of muscle fitness (MF) and leg power with cardiovascular health in youth (Janz et al., 2021; Smith et al., 2014; Artero et al., 2011). Similarly, systematic reviews and meta-analytic studies have documented beneficial association of muscular fitness with general cardiometabolic health, including central and total adiposity in children and adolescents (Garcia-Hermoso et al., 2019; Smith et al., 2014).

Despite the available evidence linking muscular fitness (leg power - LP or vertical jump power-VJP) to health of adolescents, results from previous research investigating the independent relationship of leg power and cardiorespiratory fitness (CRF) (herein referred to as fitness) with waist circumference (WC) are inconsistent. Furthermore, there is a dearth of information on the independent association of muscular fitness with CVD risk factors, particularly abdominal adiposity among adolescents. The HELENA study comprising 363 Spanish adolescents documented negative associations between both total and central fat with MF and CRF even after controlling for confounding variables (Moliner-Urdiales et al., 2011). In a study involving 9-13-year-old children from three countries (Heroux et al., 2013), abdominal obesity was negatively associated with both CRF and MF among participants, although the results varied from country to country. Yet, in another investigation, CRF but not MF was independently associated with abdominal obesity (An et al., 2021). However, both aerobic fitness and lower extremity muscle power were negatively associated with waist circumference, although the relationships between WC and MF were weaker (Gonzalez-Suarez et al., 2013; Hockstra et al., 2008). Therefore, the association of aerobic fitness and MF with abdominal adiposity is still a lingering phenomenon in the study of fat distribution among adolescents, and, it is yet to be clearly established.

Previous studies evaluating the association of muscular fitness with cardiometabolic disease risks in youth either used standing long jump or FitnessGram test battery (which included standing long jump as the only test of lower extremity muscular fitness) while vertical jump test which is considered a more robust test of muscular fitness or power (Mahar et al., 2022) was rarely used (Buchan et al., 2015). Furthermore, previous studies investigating this problem were conducted among children from high income countries with advantages of better nutrition and health care than African children. It is also possible that associations among these variables might differ for populations in different settings, hence the need for this study. The aim of this study is two-fold; firstly, to examine the associations of CRF and leg power with abdominal adiposity among adolescents in Benue state, Nigeria. Secondly, to ascertain specific cut-off points for CRF and VJP in predicting risk of abdominal adiposity among the adolescents. Information on the inter-relationships among these variables could potentially be useful for developing and implementing effective and preventive intervention programs to maintain optimal cardiometabolic health in adolescents.

METHODS

Population and Sample

This was a cross-sectional descriptive study comprising volunteer adolescents ages 12-16 years drawn from seven secondary schools in Benue State, Nigeria. The study sample size was determined using the Lorentz formula for population greater than 10000 with a prevalence of high abdominal adiposity of 9% obtained from the pretest as recommended by Pourhoseingholi, Vahedi and Rahimzadeh (2013). The minimum size calculated was 126 participants (with 95% confidence level, 5% margin of error and a confidence limit of 1.96) which was increased to 2100 because of easy access to many schools, to account for attrition rate and also to improve representativeness. The methodology highlighting the inclusion criteria, study setting, anthropometric and fitness measurements and pilot study has been previously described (Musa, Iornyor & Tyoakaa, 2022). Briefly, only participants without musculoskeletal ailments, history of CVD, and other known health problems, illness were included in the study. The study obtained ethical approval from the Health Research Ethics Committee of Benue State University (Ref. No. BSUTHMKD/HREC/2013/017). The participants gave parental/guardian written informed consent and assent before data collection. For all measurements, adherence to the ethical guidelines of the Helsinki declaration (World Medical Association, 2013) was ensured. The testing team made two visits to each participating school. The first visit was for participants to familiarize themselves with the CRF and VJ test protocols and measurement of physical characteristics. The physical fitness testing required one additional visit.

Anthropometric Measures

Participants' anthropometric characteristics were measured using standard procedures (Marfell-Jones et al., 2012). Barefoot stature was measured to the nearest 0.1 centimeter with a potable stadiometer (Model Sec-206; Seca, Birmingham, UK), body mass in light indoor clothing, without footwear, was measured to the nearest 0.1 kg using a calibrated electronic weighing scale (Model Sec-880, Seca Birmingham, UK). The medial calf and triceps skinfolds were measured using the Harpenden skinfold calipers (Creative Health Products, Ann Arbor, MI, USA). The prediction equations for black children were used to determine body fat percent (The Cooper Institute, 2017). From their BMI data, the participants were categorized as either having a healthy weight or being overweight based on revised FitnessGram data (The Cooper Institute, 2017).

Measurement of waist circumference was undertaken with a retractable tape (Lufkin type: W606PM Rosscraft, Canada) to the nearest 0.1 centimeter. Age- and sex-specific threshold for abdominal adiposity at 90th percentile was determined as recommended by the International Diabetes Federation (IDF) (Zimmet et al., 2007).

Fitness Testing

Cardiorespiratory fitness was assessed with the progressive aerobic cardiovascular endurance run (PACER) multistage fitness test protocol. The PACER is adapted from the 20-meter shuttle run test that progressively increases in intensity. In the PACER test, participants repeatedly ran forth and back between two lines drawn 20 meters apart. Participants were asked to run until exhaustion and verbally encouraged throughout the test. The number of laps completed and each participant's running speed were used to predict their CRF (Leger et al., 1988). Specific details of this test protocol and the procedure for categorizing participants into high fitness and low fitness groups based on revised FITNESSGRAM data have been described elsewhere (The Cooper Institute, 2017).

The vertical jump (VJ) test was used to measure leg power (muscular fitness) as outlined by Mcguigan (2015). After completing a general dynamic warm-up comprising activities such as jumping jack, full knee bends and body weight squats, each for 10 repetitions, participants were allowed to perform a couple of practice jumps. Applying the countermovement jump (CMJ) procedure, the participants' scores were converted to vertical jump power (VJP) values based on the prediction equation of Mahar et al. (2022). The VJ field test with CMJ protocol has been used to evaluate lower extremity muscle power by several investigators (Mahar et al., 2022; Musa, et al., 2022).

$$\text{VJP (watts)} = -1354.820 + (35.445 \times \text{VJ [cm]}) + (43.942 \times \text{body mass [kg]})$$

Detailed description of the protocol has already been published (McGuigan, 2015). The participants' gender-specific VJP receiver operating characteristic curve (ROC) cut-off data were used to group them into high and low power categories.

Pilot Test

A pilot test ascertained the test reliability and refined logistical test administration procedures. Forty adolescents aged 12 to 15 years who were not part of the actual study participated in the pilot test. All measurements were conducted in accordance with standard procedures and test reliability was determined using the Cronbach's alpha coefficients. In general, Cronbach alpha coefficients ranging from 0.864 to 0.899 were obtained thus indicating high internal consistency (Pallant, 2017).

Statistical Analysis

Before analyses, data were coded and checked for normality of distribution using the Komolgorov-Smirnov test. Data were subsequently analyzed and reported as means, standard deviations, frequency counts and percentages. Significant sex differences on all study variables were examined with the independent samples t-test. Pearson's correlation was computed to assess the relationships between the participants' dependent and independent variables. The associations of abdominal adiposity with CRF and LP, and the relative importance of CRF and LP were determined through multivariate regression models, which were all adjusted for chronological age and biological maturity. Chronological age and stature were used to estimate biological maturation based on Moore et al.'s (2015) prediction equation, which estimates maturity off-set (MO) directly. Thereafter, age at peak height velocity (APHV) was determined as the difference between MO and chronological age. First, analyses were performed in which CRF and LP were related to WC separately controlling for chronological age and MO. That is, 'unadjusted' analysis. Then another multiple linear regression analysis was conducted in which both CRF and LP were analyzed together in relation to WC, again correcting for the same confounding variables. That is, 'adjusted' analysis. Both unadjusted and adjusted analyses were performed for both genders. Receiver operating characteristic curve analysis with 95%CI was used to examine the predictive capacities of CRF and LP for risk of abdominal adiposity. Thresholds for detecting risk of abdominal adiposity were assessed through the values of area under curve (AUC), sensitivity and specificity. Swet's (1988) classification scheme was used to interpret the AUC values as highly accurate (0.9-1.00); moderate (0.7-0.9); and less accurate (<0.7). All data analyses were carried out using the IBM SPSS (Version 20, IBM Corporation, Armonk, NY, USA).

RESULTS

The total number of participants with complete data was 2047 (Girls=1087; Boys=960) out of the initial 2100, with a participation rate of 97.5%. Reasons for the attrition rate included absenteeism, ill-health and non-compliance with the study protocol. The participants' physical and performance variables (Table 1) indicates that girls had higher values in MO ($p<0.001$), WC ($p<0.001$) and most anthropometric measures ($p<0.05$) than boys. Boys had significantly greater LBM ($p=0.003$), stature ($p<0.032$), VJH ($p<0.001$), APHV ($p<0.001$), PACER ($p<0.001$) and peak VO_2 ($p<0.001$) than girls. There were no sex differences in age ($p=0.432$) and VJP ($p=0.617$). Prevalence of abdominal adiposity was 10.6% (Girls = 10.9%; Boys = 10.1%); while low fitness was 23.7% (Girls=8.7%; Boys=40.7%), and low LP was 48.0% (Girls=47.2%; Boys=49.0%).

Product-moment correlation coefficients between the dependent and independent variables were weak to moderate. The correlation coefficients between WC and the independent variables in girls and boys were: (CRF: -0.046, $p>0.066$; LP: -0.336, $p<0.001$) and (CRF: =-0.080, $p=0.007$; LP: -0.379, $p<0.001$) respectively. In general, leg power was negatively and more strongly associated with abdominal adiposity than fitness in both genders.

Results of the multivariate regression analysis are presented in Table 2. The results indicated that both CRF and

LP were significantly associated with abdominal adipose tissue after adjustment for age and maturity status (unadjusted analysis). Further adjustment for fitness did not affect the relationship between abdominal adipose tissue and LP, but additional adjustment for LP did not affect the association between the dependent variable and fitness in boys, but attenuated the significant relationship in girls. These results indicate that the observed relationship between WC and LP is independent of CRF. Furthermore, these relationships were stronger for girls than boys.

The results further indicated that in girls, LP explained 10.1% of the variation in abdominal adiposity. A unit increase in VJP resulted in a mean decrease of 1.9 cm in abdominal adiposity. However, in boys, only 5.3% of the variation in abdominal obesity was explained by LP, with a unit increase in VJP resulting in a mean decrease of 1.6 cm in abdominal obesity.

Results of the ROC analyses are shown in Table 3. The AUCs for LP were significant ($p<0.05$) in both genders, while those of CRF were not ($p>0.05$). The LP thresholds in girls and boys were 1330W and 1329W, respectively.

DISCUSSION

This study has four main findings: First, the prevalent rate of abdominal adiposity of 10.6% among the adolescents is comparable to rates documented in previous studies involving adolescents elsewhere, and, it is reportedly, higher in females. Second, the association of independent variables with WC is weak to moderate, with LP demonstrating a stronger relationship. Third, CRF and LP are independently associated with WC. Finally, only LP had significant AUC and a better capacity for detecting risk of abdominal adiposity in both sexes.

The prevalence rates of abdominal adiposity of 10.9% and 10.1% for girls and boys documented in this study are comparable to the rates of 10.1% and 10.0% reported for Iranian girls and boys, respectively (Esmaillazed et al., 2006). However, the prevalence rates of 26.0% and 22.0% for American girls and boys respectively (de Ferranti et al., 2004) are strikingly higher than the rates found in this study.

Findings from this study indicate that both CRF and LP were associated with WC but the relationship of LP with the dependent variable was stronger. Our results agree with those of some previous studies (Slotte et al., 2021; Buchan et al., 2015) but are at variance with those of other investigators (Gonzalez-Suarez et al., 2013; Hoekstra et al., 2008). In a study involving 1042 Filipino pre-adolescents, Gonzalez-Suarez and Co-workers (2013) documented weak relationships between CMD risk, including WC, CRF and muscle fitness, but the relationship with CRF and the dependent variable was stronger. Similarly, Hoekstra and colleagues reported a stronger association between CRF and WC than that between muscle fitness and WC among Northern Irish adolescents. These previous results suggest that CRF was more important than muscle fitness in predicting cardiometabolic disease and abdominal adiposity in the pediatric population. Unlike in the developed societies with availability of weight

Table 1. Characteristics of the participants according to gender (n = 2047)

Variable	Combined (n = 2047)	Girls (n = 1087)	Boys (n = 960)	t-value	*p*-value
Age (y)	13.6 ± 1.3	13.6 ± 1.3	13.6 ± 1.3	0.786	0.432
APHV (y)	13.4 ± 1.1	12.6 ± 0.7	14.2 ± 0.7	50.075	<0.001
Stature (cm)	150.3 ± 11.6	150.8 ± 11.0	149.7 ± 12.2	2.149	0.032
MO (y)	0.2 ± 1.4	1.0 ± 1.0	-0.6 ± 1.0	33.6	<0.001
Body mass (kg)	43.5 ± 9.0	44.2 ± 8.7	42.6 ± 9.3	3.931	<0.001
BMI ($kg.m^{-2}$)	19.3 ± 3.8	19.5 ± 3.7	19.1 ± 3.9	2.319	0.021
Fat (%)	16.0 ± 6.5	18.4 ± 5.6	13.4 ± 6.4	18.597	<0.001
WC (cm)	66.2 ± 8.4	67.1 ± 8.2.	65.1 ± 8.5	5.460	<0.001
LBM (kg)	36.4 ± 7.4	35.9 ± 6.5	36.9 ± 8.3	2.935	0.003
VJH (cm)	23.8 ± 7.6	22.7 ± 7.1	25.0 ± 7.9	6.774	<0.001
VJP (w)	1397.9 ± 507.9	1392.6 ± 481.7	1403.9 ± 536.2	0.501	0.617
PACER (lap)	34.7 ± 17.8	32.1 ± 18.3	37.7 ± 16.7	7.161	<0.001
Peak VO_2 ($ml.kg^{-1}.mim^{-}$)	42.7 ± 6.4	41.7 ± 6.6	43.7 ± 6.0	7.227	<0/001

APHV: age at peak height velocity; MO: maturity onset; BMI: body mass index; WC: waist circumference; LBM: lean body mass; VJH: vertical jump height; VJP: vertical jump power; PACER: progressive aerobic cardiovascular endurance run

Table 2. Standardized regression coefficients examining the relationship among CRF, LP and WC

Variable	Girls (n = 1087)				Boys (n = 960)			
	Unadjusted	*p*-value	Adjusted	*p*-value	Unadjusted	*p*-value	Adjusted	*p*-value
CRF	-0.061	0.034	-0.049	0.091	-0.109	<0.001	-0.101	0.001
LP	-0.339	<0.001	-0.307	<0.001	-0.348	<0.001	-0.262	<0.001

Unadjusted: correcting for age and maturity status. Adjusted: correcting for all covariates and either CRF or LP

Table 3. ROC curve analysis for risk of abdominal adiposity among participants (n = 2047)

Gender	Variable	AUC	95%CI	Cut-point	Se	SP	*p*-value
Girls	CRF	0.505	0.479-.540	40.3	0.506	0.497	0.783
	LP	0.692	0.661-.724	1330	0.691	0.418	<0.001
Boys	CRF	0.490	0.449-.532	43.1	0.491	0.524	0.630
	LP	0.644	0.604-.683	1329	0.642	0.459	<0.001

CRF: cardiorespiratory fitness; LP: leg power; AUC: area under curve

training machines where the youth could engage more in resistance exercises (Gonzalez, et al., 2013), Nigerian youth do more of cardiovascular exercises which require little or no equipment, at the expense of strength-related exercises. Hence the reason for leg power demonstrating a stronger relationship with WC than CRF among the present study participants. The comparatively higher prevalence of low leg power (48%) in relation to low CRF (23.7%) among the Nigerian adolescents reinforces this position. Notably, the measurement protocols, age and sampling variations are probably reasons for the inconsistencies in results of other studies compared with the present findings.

Our results show that low leg muscle fitness is a more serious problem among this cohort of adolescents. Results of the ROC analysis in which only leg power demonstrated a better discriminatory capacity to detect risk of abdominal adipose tissue also confirms this. These results highlight the need to place emphasis on this physical fitness component among this group of adolescents. There is compelling evidence that muscle power is an essential aspect of health-related physical fitness which should be encouraged to maintain positive or optimal health in young persons (Janz et al., 2021; Smith et al., 2014).

Based on the present findings, it may be reasonable to believe that the association of low CRF and more importantly, low LP with abdominal adiposity may be a result of reduced physical activity (Artero et al., 2011; Moliner-Urdiales et al., 2011). Poor levels of fitness and LP could increase the risk of abdominal adipose tissue and its co-morbidities such as type 2 diabetes mellitus and hypertension in adolescents. Clearly, evidence has shown that muscle fitness is linked to cardiometabolic health in children and adolescents (Baptista et al., 2022; Janz et al., 2021). Consequently, it is imperative for stakeholders in pediatric health to use the current physical activity guidelines for youth to encourage them to participate in regular physical activities that enhance muscle-strengthening to promote muscle fitness (Welk et al., 2022; United States Department of Health and Human Services - USDHHS, 2018). Evidence from this and other studies should serve as a stimulus for effective public health promotion efforts aimed at reducing adolescent abdominal obesity by encouraging participation in physical activity that improve muscular fitness and CRF (Bull et al., 2020).

The findings of our study should be interpreted cautiously based on a number of constraints. First, the cross-sectional design is an obvious limitation as it precludes determination of causality. Second, our estimate of abdominal adipose tissue was obtained by field methods which may be less accurate than laboratory methods such as the computed tomography, dual energy X-ray absorptiometry and other imaging techniques. But these laboratory methods are not feasible for mass screening and every day clinical practice. However, the use of health-related and ROC cut-off points instead of median-split for the study variables are the main strengths of this study. This approach indicated that the study participants who met the health standards demonstrated better abdominal adipose tissue profiles than those who fell short of the benchmark.

CONCLUSIONS

Findings from this study indicate that both LP and CRF were independently associated with abdominal adipose tissue in Nigerian adolescents, but LP demonstrated a stronger association particularly in girls. The combination of cardiorespiratory fitness and leg power in predicting abdominal adiposity was modest. Gender- wise, LP best predicted abdominal adiposity in girls while age was the predictor of abdominal adiposity in boys. These results suggest that health promotion efforts targeting the reduction of abdominal adipose tissue in adolescents should include muscular fitness training, which has often been neglected in favor of cardiorespiratory fitness. Further research is needed to clarify these relationships in diverse youth populations, and to examine the effect of a lower body muscular training program on body fat distribution.

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DATA AVAILABILITY STATEMENT

Data for this study are available with the corresponding author.

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