The Association Between Abdominal Fat, Cardiorespiratory Fitness, and Clinical Markers of Metabolic Syndrome

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Abstract: Our purpose was to determine the association between abdominal fat and cardiorespiratory fitness (CRF) on markers of metabolic syndrome (MetS) total cholesterol (TC), high-density lipoprotein (HDL-C), low-density lipoprotein (LDL-C), triglycerides (TG), glucose, and blood pressure. We conducted a retrospective study on 165 adults (108 men) in which correlations between waist girth (WG), CRF and blood variables were determined. The cohort was partitioned by gender into quartiles and again by WG and differences in markers of MetS were compared across quartiles by ANOVA and by ANCOVA to determine the influence of CRF. Males in the lowest WG quartile exhibited greater HDL-C and lower diastolic blood pressure vs. the highest quartile (p < 0.05). TG were lower in the lowest vs. the third and highest quartile (p < 0.05), and glucose was greater in the highest vs. the first and second quartiles (p < 0.05). Females in the second WG quartile exhibited higher HDL-C vs. the highest quartile, and TG, glucose, systolic and diastolic blood pressure were lower in the lowest vs. the highest quartile (p < 0.05). After adjusting for CRF, diastolic blood pressure across WG in males were no longer significant, and HDL-C and TG quartile differences were no longer significant in females. We confirm WG as an important correlate of clinical markers of MetS in adults. CRF mitigates relationships between WG and clinical markers of cardio-metabolic risk in men and women.

Keywords: Metabolic Syndrome, Cardiovascular Fitness, Body Fat, Waist Circumference

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1. Introduction

Metabolic Syndrome (MetS) represents a constellation of interrelated risk factors of metabolic origin that are linked to insulin resistance and strongly associated with the development and severity of type 2 diabetes mellitus, the progression of diabetic nephropathy, and with an increased risk for overt cardiovascular disease and stroke [1]. In the United States, the prevalence of MetS in the population using National Health and Nutrition Examination Survey (NHANES) data from 2011 to 2016 showed an alarming 34.7% for the general population and similar proportions for men (35.1%) and women (34.3%) [2]. There has been an increase ~10% over a decade (~80 million adults) [3], which does not represent an encouraging scenario for a country that is making efforts to combat this cluster of diseases in the population.

Clinicians and health care practitioners utilize anthropometric measures such as waist girth (WG) or waist circumference to identify individuals at increased risk for cardio-metabolic dysfunction [4]. There are WG cut-off points established for men and women according to several organizations [5, 6]; however, the deleterious effect of increasing abdominal fat on cardiometabolic health is continuous.

Cardiorespiratory fitness (CRF) is independently associated with the incidence of MetS in both, men and women [7-9]. CRF is a strong predictor of mortality even with concomitant cardiovascular and cancer disease [10, 11] and is more protective against developing cardiovascular disease outcomes than merely increasing amounts of physical activity [12]. CRF offers a protective effect in all-cause and cardiovascular disease mortality in people with MetS [13]. Meta-analytical evidence shows that CRF attenuates the effects of each MetS risk factor, thus resulting in substantial protection against its development [14]. It is known that for every 1-MET increase (3.5 ml·kg⁻¹·min⁻¹) in CRF is associated with 10 to 25% increase in survival from cardiovascular diseases [15]. Likewise, CRF has well-known strong and inverse relationship with many of the health markers described in MetS (e.g., reduced waist girth, dyslipidemia) [16-18]. Unlike WG and many cardiometabolic disease risk markers there are no known clinical cut-off points for CRF or criteria for establishing protection against cardio-metabolic dysfunction. The purpose of this study was to retrospectively characterize the association between WG, as a surrogate of abdominal fat, and relative CRF on clinical markers of MetS in men and women. Our approach was to partition male and female cohorts into quartiles based on WG and then to examine the influence of CRF as a modulator of cardio-metabolic risk across waist girth quartiles.

2. Methods

2.1 Participants

Anonymous data from information collected on 165 adults (108 males and 57 females), attending a university-based health and fitness assessment program were retrospectively reviewed. The study was
approved by the Institutional Review Board of Auburn University in accordance with expedited research described in title 45 of the Code of Federal Regulations 46.110 of the United States of America regulations. All participants completed a health history questionnaire, a medical examination, blood sampling, body composition analysis, and a graded exercise test to determine CRF and heart rate, systolic blood pressure (SBP) and diastolic blood pressure (DBP) responses to exercise of increasing intensity. The assessments were performed for the purpose of providing individual health and fitness information and exercise training recommendations for clients of a university-based community service program.

2.2 Procedures

Anthropometric and body composition. Height (cm) and body weight (kg) were measured by stadiometer and a calibrated medical scale, respectively. Waist and hip circumferences were assessed with a plastic-coated cloth measuring tape (cm). Relative (%) and absolute (g) values of total and regional lean and fat tissue were estimated using Dual-energy X-ray absorptiometry (DXA, Lunar system, General Electric, Fairfield, CT) with enCORE software, version 6.0. WG quartiles (Q1) were independently created for males and females. For males, Q1 included waist values < 89 cm, Q2 values between 89.1 and 96.1 cm, Q3 values between 96.2 and 103.9 cm, and Q4 values > 104 cm. For females, Q1 included waist values < 71.3 cm, Q2 values between 71.4 and 75.5 cm, Q3 values between 75.6 and 83.6 cm, and Q4 values > 83.7 cm.

Physiological testing for cardiorespiratory fitness. The standardized Bruce treadmill protocol [6] was used to determine CRF. Total treadmill time was recorded to estimate peak absolute (l·min⁻¹) and relative (mI·kg⁻¹·min⁻¹) oxygen consumption (VO₂peak) as measures of CRF. Heart rates were continuously measured during the test and SBP and DBP were obtained manually at rest and during the last 30 s of each exercise stage [6].

Blood Sampling. Blood samples were obtained in the morning after an 8- to 10-h fast and prior to undergoing physiological testing for CRF. Blood samples were collected in serum-separator tubes and analysed at a Centers for Disease Control and Prevention certified reference laboratory. Blood analyses included total cholesterol (TC), high-density lipoprotein (HDL-C), low-density lipoprotein (LDL-C), triglycerides (TG), and glucose.

2.3 Statistical analysis

Statistical analysis was performed with the IBM-SPSS Statistics, version 21 (IBM Corporation, Armonk, New York). Values are presented as mean and standard deviation (M ± SD). Independent samples t-tests were used to determine gender differences in anthropometric, physiological and blood variables.

Pearson-product moment correlations between regional body fat, WG, physiological (i.e., VO₂peak, blood pressure), blood and CRF were calculated. ANOVA tests were used to determine global differences in cardio-metabolic risk factors between WG quartiles. Tukey’s post hoc analyses were used to follow-up global differences. ANCOVA were used to determine whether differences in the dependent variables between WG quartiles remained by using CRF as covariate. Statistical significance for all tests were set a priori at p ≤ 0.05.

3. Results

Descriptive statistics for anthropometric, physiological and blood variables by gender are presented in table 1. The sample was comprised by males (mean age = 49.0 ± 10.2 yr., 95%CI = 47.1, 51.0) and females (mean age = 47.2 ± 12.5 yr., 95%CI = 43.8, 50.5). Complete data for WG were obtained for 108 males and 55 females. Physiological and blood variables were collected for 108 males and 57 females. Independent samples t-tests revealed no significant gender differences in age, gynoid fat content, TC, LDL-C, and relative CRF (p > 0.05) (Table 1).

Significant correlations between WG were observed in males for body fat % (r = 0.76, p ≤ 0.0001, Figure 1A), android (r = 0.90, p ≤ 0.0001, Figure 1B) and gynoid (r = 0.81, p ≤ 0.0001) patterns of fat distribution, HDL-C (r = -0.37, p = 0.01), TG (r = 0.29, p = 0.01), blood glucose (r = 0.37, p = 0.01), SBP (r = 0.22, p = 0.05), DBP (r = 0.27, p = 0.01), and CRF (r = -0.60, p ≤ 0.001, Figure 1C).

Significant correlations between WG were observed in females for body fat % (r = 0.61, p ≤ 0.0001, Figure 1D), android (r = 0.89, p ≤ 0.0001, Figure 1E) and gynoid (r = 0.59, p ≤ 0.0001) patterns of fat distribution, TG (r = 0.30, p = 0.05), blood glucose (r = 0.45, p = 0.01), SBP (r = 0.46, p = 0.01),
DBP (r = 0.36, p = 0.01), and CRF (r = -0.49, p ≤ 0.0001, Figure 1F).

In males, TC (p = 0.362) and LDL-C (p = 0.171) did not differ between WG quartiles. HDL-C were greater in Q1 vs. Q4 (p = 0.002), TG concentration were lower in Q1 vs. Q3 (p = 0.010) and Q4 (p = 0.008), and blood glucose were lower in Q1 vs. Q3 (p = 0.010), Q1 vs. Q4 (p = 0.002), and Q2 vs. Q4 (p = 0.031). SBP were similar across WG quartiles (p = 0.063); however, DBP were lower in Q1 vs. Q4 (p = 0.023). CRF were incrementally lower with increasing waist girth quartiles (p < 0.008 to p < 0.0001) (Table 2).

In females, TC (p = 0.512) and LDL-C (p = 0.559) did not differ between WG quartiles. HDL-C were higher in Q2 vs. Q4 (p = 0.042), TG were lower in Q1 vs. Q4 (p = 0.048), and blood glucose concentration were lower in Q1 vs. Q4 (p ≤ 0.0001). Both, SBP (p = 0.013) and DBP (p = 0.015) were lower in Q1 vs. Q4. CRF was greater in Q1 vs. Q4 (p = 0.005) and Q2 vs. Q4 (p = 0.004) (Table 2).

In males, DBP was no longer significantly different between waist quartiles after adjusting for CRF (p = 0.054) (Table 3). In females, blood glucose concentrations (p = 0.004), SBP (p = 0.016) and DBP (p = 0.023) remained significantly different between waist quartiles after adjusting for CRF. HDL-C and TG were no longer significantly different between waist quartiles after adjusting for CRF (Table 3).

### Table 1. Anthropometric, physiological and blood characteristics for participants (n= 165) and independent samples t-test results comparing gender.

| Variable                  | Males (n = 108) | Females (n = 57) | p ≤  
|---------------------------|-----------------|-----------------|------
| **Age (yr)**              | Mean ± SD       | Min             | Max  | Mean ± SD       | Min             | Max  |  
|                           | 49.0 ± 10.2     | 30.0            | 69.0 | 47.2 ± 12.5     | 22.0            | 73.0 | 0.3010  
| **Height (cm)**           | 176.0 ± 6.7     | 157.5           | 191.3| 163.8 ± 6.0     | 151.1           | 182.9| 0.0001  
| **Weight (kg)**           | 90.3 ± 18.6     | 64.5            | 149.8| 66.8 ± 12.4     | 47.5            | 126.8| 0.0001  
| **BMI (kg·m⁻²)**          | 29.0 ± 5.1      | 21.0            | 45.7 | 24.9 ± 4.0      | 18.8            | 37.9 | 0.0001  
| **DXA Fat (%)**           | 28.8 ± 7.2      | 10.0            | 43.0 | 35.9 ± 7.7      | 19.0            | 49.0 | 0.0001  
| **Android fat (kg)**      | 2.9 ± 1.4       | 0.5             | 7.73 | 1.8 ± 0.9       | 0.4             | 5.6  | 0.0001  
| **Gynoid fat (kg)**       | 4.2 ± 1.8       | 1.2             | 10.8 | 4.8 ± 1.5       | 2.0             | 9.4  | 0.0580  
| **Waist (cm)**            | 97.4 ± 12.1     | 76.2            | 132.1| 78.2 ± 10.4     | 60.9            | 118.1| 0.0001  
| **Hip (cm)**              | 104.2 ± 10.9    | 85.1            | 147.3| 99.6 ± 11.6     | 61.7            | 143.5| 0.0130  
| **VO₂peak (l·min⁻¹)**     | 3.3 ± 0.7       | 1.6             | 5.2  | 2.3 ± 0.5       | 1.1             | 3.5  | 0.0001  
| **VO₂peak (ml·kg⁻¹·min⁻¹)**| 37.6 ± 9.7     | 20.5            | 62.2 | 34.8 ± 8.7     | 18.0            | 55.7 | 0.0780  
| **Systolic BP (mmHg)**    | 127.3 ± 15.1    | 90.0            | 200.0| 118.9 ± 13.8    | 92.0            | 150.0| 0.0010  
| **Diastolic BP (mmHg)**   | 79.8 ± 8.1      | 58.0            | 100.0| 73.4 ± 8.2      | 56.0            | 90.0 | 0.0001  
| **TC (mmol·l⁻¹)**         | 4.9 ± 0.9       | 2.8             | 7.1  | 5.1 ± 1.1       | 3.4             | 8.9  | 0.3200  
| **LDL-C (mmol·l⁻¹)**      | 2.9 ± 0.7       | 1.1             | 5.9  | 2.9 ± 1.0       | 1.5             | 6.5  | 0.8330  
| **HDL-C (mmol·l⁻¹)**      | 1.3 ± 0.3       | 0.7             | 2.4  | 1.7 ± 0.4       | 1.0             | 2.5  | 0.0001  
| **Triglyceride (mmol·l⁻¹)**| 1.6 ± 0.9     | 0.4             | 4.4  | 1.1 ± 0.7       | 0.5             | 4.4  | 0.0001  
| **Glucose (mmol·l⁻¹)**    | 1.1 ± 0.2       | 0.8             | 1.6  | 1.0 ± 0.1       | 0.8             | 1.6  | 0.0001  

Note: BMI = Body mass index, DXA = dual x-ray absorptiometry, VO₂peak = estimated peak oxygen consumption, BP = Blood pressure, TC = Total cholesterol, LDL-C= Low-density lipoprotein cholesterol, HDL-C= High-density lipoprotein cholesterol.
Figure 1. Scatterplot diagrams and correlations between waist circumferences and selected measures of total and abdominal body fat and cardiorespiratory fitness for males (panel A, B, C) and females (panel D, E, F).

Table 2. Selected anthropometric and blood characteristics by waist quartiles (cm) unadjusted for estimated relative (ml·kg⁻¹·min⁻¹) cardiorespiratory fitness (Values are presented as means ± 1 SD. Means with different superscript letters are significantly different at p < 0.05).

<table>
<thead>
<tr>
<th>Males (n = 108)</th>
<th>Waist quartiles (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q₁ (&lt; 89)</td>
</tr>
<tr>
<td>Variable</td>
<td>(n = 31)</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>24.3 ± 1.8ᵃ</td>
</tr>
<tr>
<td>DXA Fat (%)</td>
<td>21.7 ± 5.8ᵃ</td>
</tr>
<tr>
<td>Android fat (kg)</td>
<td>1.6 ± 0.6ᵃ</td>
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</tbody>
</table>
Table 3. Blood and physiological characteristics by waist quartiles (cm) adjusted for estimated relative (ml·kg\(^{-1} \cdot \text{min}^{-1}\)) cardiorespiratory fitness (Values are presented as adjusted means ± 1 SD. Means with different superscript letters are significantly different at \(p < 0.05\)).
Females with smaller WG showed higher HDL-C and lower TG, glucose, SBD, and DBP than males in every matching Qth category (Table 3). This finding supports the association between lower relative adiposity as estimated by WG and a better metabolic and physiological profile in male and females because of exercise aimed at improving CRF. Indeed, regularly practiced exercise training reduces the prevalence of MetS in adults by 30.5% [17] and cardiorespiratory exercise training regimens appear to have significant effects in reducing abdominal adiposity, decreasing subcutaneous and visceral adipose tissue and other biochemical clinical markers of MetS [14]. Due to the considerable public health burden associated with MetS, physical activity to improve CRF should be promoted as a primary prevention strategy for ameliorating MetS [12, 13, 24]. High-intensity interval training (HIIT), aerobic and resistance training, have been recently found in meta-analytic, systematic and narrative reviews to be valid and successful strategies for reducing and controlling cardio-metabolic risk factors associated with MetS [14, 18, 25].

The exact dose-response of these exercise strategies for desirable changes in metabolic and other markers of MetS remains to be determined for several populations. Cardiorespiratory exercise reduces clinical markers of MetS in postmenopausal women in a dose-response manner [26]. For instance, women completing six months of low-to-moderate intensity cardiorespiratory exercise significantly reduced waist circumference, fasting glucose, and systolic blood pressure [26]. However, a meta-analysis suggests that HIIT interventions almost double the CRF compared to cardiorespiratory exercise significantly reduced waist circumference, fasting glucose, and systolic blood pressure [26].
pressure, and increase HDL-C and VO2peak [27]. Therefore, modest improvements in clinical markers of the cardio-metabolic profile might be expected on those with MetS after engaging in low-intensity exercise, and higher benefits are to be expected from increasing the intensity of their workouts.

Consistent evidence shows that physical activity ameliorates cardio-metabolic risk factors and that the dose of physical activity necessary to improve health may be much less than needed for increasing CRF. Therefore, it is possible that our present findings of only modest influence of CRF on the cardiometabolic disease risk associated with increasing waist girth is due, in part, to benefits of physical activity on health that occur at a lower dose than what is needed to improve CRF. Other major limitations of this study are that we did not account for life-style factors related to MetS such as sleep, nutrition, and stress management.

5. Conclusion

This study lends support for the notion that WG is a surrogate measure for predicting MetS regardless of gender, and that this association has been consistently found in males and females of different age and ethnic groups worldwide. We report that our primary finding provides consistency to the literature: CRF, attained primarily as a direct result of modifiable health behaviour, diminishes relationships between WG and clinical markers of cardio-metabolic risk in men and women.

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Authors Contribution
P.W. Grandjean and F. Araya-Ramírez – study design, data collection, conceptualization; J. Moncada-Jiménez – statistical analysis, interpretation of results, draft preparation; J. K. Taylor – interpretation of results, draft preparation. All the authors read and approved the final version of the draft.

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Written consent was obtained from the participants

Ethics Approval
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Availability of data and material
No additional data are available.

Conflict of interest
The authors have no conflicts of interest to declare that are relevant to the content of this article.

Does this article screened for similarity?
Yes

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