Published in final edited form as:

Med Sci Sports Exerc. 2013 January ; 45(1): 163–169. doi:10.1249/MSS.0b013e3182699239.

METABOLIC SYNDROME AND DAILY AMBULATION IN CHILDREN, ADOLESCENTS, AND YOUNG ADULTS

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Abstract

Purposes—To compare daily ambulatory measures in children, adolescents, and young adults with and without metabolic syndrome, and to assess which metabolic syndrome components, demographic measures, and body composition measures are associated with daily ambulatory measures.

Methods—Two-hundred fifty subjects between the ages of 10 and 30 years were assessed on metabolic syndrome components, demographic and clinical measures, body fat percentage, and daily ambulatory strides, durations, and cadences during seven consecutive days. Forty-five of the 250 subjects had metabolic syndrome, as defined by the International Diabetes Federation.

Results—Subjects with metabolic syndrome ambulated at a slower daily average cadence than those without metabolic syndrome (13.6 ± 2.2 strides/min vs. 14.9 ± 3.2 strides/min; $p=0.012$), and they had slower cadences for continuous durations of 60 minutes ($p=0.006$), 30 minutes ($p=0.005$), 20 minutes ($p=0.003$), 5 minutes ($p=0.002$), and 1 minute ($p=0.001$). However, the total amount of time spent ambulating each day was not different ($p=0.077$). After adjustment for metabolic syndrome status, average cadence is linearly associated with body fat percentage ($p<0.001$) and fat mass ($p<0.01$). Group difference in average cadence was no longer significant after adjusting for body fat percentage ($p=0.683$) and fat mass ($p=0.973$).

Conclusion—Children, adolescents, and young adults with metabolic syndrome ambulate more slowly and take fewer strides throughout the day than those without metabolic syndrome, even though the total amount of time spent ambulating is not different. Furthermore, the detrimental influence of metabolic syndrome on ambulatory cadence is primarily a function of body fatness.

Keywords

Ambulation; body fat; children; metabolic syndrome; physical activity

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The results of the present study do not constitute endorsement by ACSM.

INTRODUCTION

Metabolic syndrome is a condition linking insulin resistance, dyslipidemia, hyperglycemia, and hypertension(7) that increases the risk of developing diabetes,(18, 24) cardiovascular disease,(20, 25) and subsequent cardiovascular morbidity and mortality.(8) Therefore, it is an early marker of increased risk of atherosclerosis and its' associated complications. Metabolic syndrome was prevalent in 21.8% of people aged 20 years or older in the Third National Health and Nutrition Examination Survey (NHANES) obtained between 1988 and 1994,(12) which increased to 34.3% in the 2003–2006 NHANES observation.(13) The prevalence of overweight children and adolescents in the NHANES study increased from 5% between 1976 and 1980 to 15% between 1999 and 2000.(30) Thus, it is not surprising that metabolic syndrome is now becoming prevalent in children and adolescents,(6) placing them at heightened cardiovascular risk at very young age. The International Diabetes Federation recently recommended definitions for each component of metabolic syndrome in children and adolescents, consisting of having abdominal obesity plus at least two of the other four components: hypertriglyceridemia, low HDL cholesterol, hyperglycemia, and hypertension.(39) Since abdominal obesity is the hallmark measure of metabolic syndrome, the role that physical activity may have in altering visceral adiposity and metabolic syndrome is apparent.(33)

Regular physical activity in prospective observational studies is one lifestyle modification that can favorably impact cardiovascular health outcomes, including cardiovascular disease, thromboembolic stroke, hypertension, type 2 diabetes mellitus, and obesity.(23) As such, it is recommended that to promote and maintain health, all healthy adults between 18 and 65 years of age need moderate intensity physical activity for a minimum of 30 minutes on five days each week.(14, 19) For children and adolescents between five and 17 years of age, it is recommended that moderate intensity physical activity should be accumulated for at least 60 minutes per day, although some health benefits may occur with at least 30 minutes per day.(21, 37) As described in a systematic review,(21) it is not clear whether physical activity lessens the risk of developing metabolic syndrome in children and adolescents. Two studies which used self-reported measures of physical activity found weak or modest associations with metabolic syndrome,(22, 32) whereas other studies that used objective measures from accelerometers found significant and stronger associations.(2, 4) However, the pattern of physical activity in terms of both volume and intensity on individual components of metabolic syndrome has not been studied in children and adolescents. This information is important for physical activity recommendations to lessen the risk of developing metabolic syndrome and its' components.

We have utilized a step activity monitor to quantify not only the total amount of daily ambulation, but also the cadence of daily ambulation which serves as a measure of intensity.(5, 16, 17) The purposes of this study are (1) to compare daily ambulatory measures in children, adolescents, and young adults with and without metabolic syndrome, and (2) to assess which metabolic syndrome components, demographic measures, and body composition measures are associated with daily ambulatory measures. We hypothesize that objectively measured daily ambulatory cadences are lower in subjects with metabolic syndrome, particularly in those with higher values of body fat percentage.

METHODS

Subjects

IRB Approval, Informed Consent, and Child's Assent—The procedures used in this study were approved by the Institutional Review Board at the University of Oklahoma Health Sciences Center (HSC). For subjects younger than 18 years of age, both the child and

parent or legal representative agreed to participate by signing the child's assent form. Subjects 18 years of age and older signed the informed consent form.

Recruitment—A total of 250 healthy subjects between 10 and 30 years of age participated at the General Clinical Research Center (GCRC) and the Children's Medical Research Institute (CMRI) Diabetes and Metabolic Research Program from September, 2006 to November, 2009. The subjects were recruited by local newspaper advertisements, university email advertisements, and informational flyers distributed in Oklahoma City and surrounding areas.

Medical Screening through History, Physical Examination, and

Anthropometry—Subjects were evaluated during a medical history and physical examination. Demographic information, pubertal status by Tanner stage, height, weight, body mass index, cardiovascular risk factors, co-morbid conditions, blood samples, and a list of current medications were obtained. Waist and hip circumferences were measured and recorded to the nearest millimeter by trained technicians using a plastic measuring tape.(11, 36

Inclusion and Exclusion Criteria—Subjects were included in this study if they met the following criteria: (a) between 10 and 30 years of age, (b) a Tanner Stage of 2 or greater for boys and girls, and (c) subjects were ambulatory. Subjects were excluded for the following criteria: (a) under treatment for hypertension, (b) under treatment for dyslipidemia, (c) current smoking, (d) insulin or non-insulin dependent diabetes mellitus, (e) use of oral contraceptives, and (f) history of any form of cardiovascular disease, pulmonary disease, renal disease, liver disease, or active cancer.

Metabolic Syndrome Groups—According to the International Diabetes Federation,(7, 39) metabolic syndrome in children and adolescents is defined as having abdominal obesity plus at least two of the other four components of metabolic syndrome consisting of elevated triglycerides, reduced HDL cholesterol, elevated blood pressure, and elevated fasting glucose. Abdominal obesity in children and adolescents between 10 and 15 years of age was defined as a waist circumference value 90th percentile of age, sex, and ethnicity norms, or the adult cutoff point, whichever is lower. For subjects 16 years of age and older, the adult criteria was used to define abdominal obesity, consisting of a waist circumference of 94 cm for males and 80 cm for females. Of the remaining four components of metabolic syndrome, the adult definitions of elevated triglycerides (> 150 mg/dl), elevated blood pressure (> 130/85 mm Hg), and elevated fasting glucose (> 100 mg/dl) were utilized. Reduced HDL cholesterol in children and adolescents between 10 and 15 years of age was defined as a value < 40 mg/dl, whereas in those 16 years of age and older the adult criteria of < 40 mg/dl in males and < 50 mg/dl in females was utilized. Of the 250 subjects included in this study, 45 (18%) screened positive for metabolic syndrome, whereas the remaining 205 (82%) screened negative.

Measurements

Ambulatory Activity Monitoring

Instrumentation and Procedures: Daily ambulatory strides, durations, and cadences were assessed using a step activity monitor (Step Watch 3, Orthocare Innovations, Oklahoma City, OK) as previously described.(15) Ambulatory activity was measured during seven consecutive days in which subjects were instructed to wear the monitor during waking hours and to remove it before retiring to bed. The step activity monitor was attached to the right ankle above the lateral malleolus using elastic Velcro straps, and continuously recorded the

number of steps taken on a minute-to-minute basis. The accuracy of the step activity monitor exceeds $99 \pm 1\%$ in older adults,(15) as well as in children.(27

Variables Obtained from the Step Activity Monitor: The step activity monitor records the number of ambulatory strides taken per minute for each minute throughout a 24-hour period. After downloading data from the step activity monitor to a computer, the software program displays the number of strides taken and the number of minutes spent ambulating each day, from which a daily average cadence is calculated. Any minute in which ambulation occurred (i.e., at least one stride was recorded) was defined as an active minute, and the total number of strides were divided by the total number of active minutes to yield an average cadence of ambulation. The daily ambulatory strides and time are further analyzed by the software program, and are quantified into the following variables: maximum cadence for 60, 30, 20, and 5 continuous minutes of ambulation each day, maximum cadence for 1 minute of ambulation each day (i.e., the minute having the single highest cadence value each day), and peak ambulatory index obtained by ranking all minutes of the day according to cadence, and then taking the highest 30 values. All of these outcome measures are recorded for each day, and then the daily values are averaged over the seven-day monitoring period. In apparently healthy subjects, the test-retest intraclass reliability coefficient for the measurement of total daily strides and total daily minutes of activity over the 7-day period are $R = 0.94$ and $R = 0.91$, respectively.(15) The intraclass reliability coefficients for the remaining variables pertaining to daily ambulatory cadences range from $R = 0.83$ to $R = 0.94$.(15

Body-Composition Assessment—Following an overnight fast of at least eight hours, body fat percentage, fat mass, and fat-free mass were obtained using a BC-418 eight-electrode bio-electrical impedance analysis device (Tanita Corp., Tokyo, Japan).(28, 31, 34) Subjects stood barefoot on the base of the unit, which has two stainless-steel rectangular foot-pad electrodes fastened to a metal platform set on force transducers. During this measurement, subjects held hand-grip electrodes. The system has a total of eight electrodes, two for each hand and foot. All electrodes are connected to a digital circuit board. Age, height, and body type (all classified as standard and none classified as athletic) were entered for each subject for calculation of body fat percentage. The assessment of body composition through bio-electrical impedance using model BC-418 has been validated against measurements obtained from dual-energy X-ray absorptiometry in males and females ranging in age from 6 to 64 years.(31

Statistical Analyses

An independent t-test was used to compare the means of continuous measures between the metabolic syndrome group and the control group. A single degree of freedom Chi-square test was used to compare the proportions of categorical measures between the two groups. Analysis of covariance (ANCOVA) was used to obtain adjusted means, and to examine the differences between the two groups for daily average cadence and daily strides, adjusted for each covariate individually. Multiple linear regression procedures with the pairing of metabolic syndrome status and each individual covariate and metabolic syndrome component (e.g., age, weight, elevated fasting glucose, etc.) serving as the independent variables, and daily average cadence and daily strides serving as the dependent variables were used to obtain slopes and partial R-square values. All analyses were performed using the NCSS statistical package (NCSS Inc, Kaysville, UT).

RESULTS

No significant differences were observed between the two groups for age ($p = 0.437$), height ($p = 0.096$), sex ($p = 0.445$), and race ($p = 0.072$) (Table 1). The metabolic syndrome group had higher values for body mass index ($p < 0.001$), waist/hip ratio ($p < 0.001$), body fat percentage ($p < 0.001$), fat mass ($p < 0.001$), and fat free mass ($p < 0.001$). By definition, all subjects with metabolic syndrome had abdominal obesity, which was a higher prevalence than those without metabolic syndrome ($p < 0.001$). As expected, those with metabolic syndrome had a higher prevalence of the components of metabolic syndrome, consisting of elevated fasting glucose ($p < 0.001$), elevated blood pressure ($p = 0.002$), elevated triglycerides ($p < 0.001$), and reduced HDL cholesterol ($p < 0.001$).

As shown in Table 2 the groups were significantly different on each measure of ambulatory activity during a 7-day monitoring period, except for the daily ambulatory time ($p = 0.077$). The metabolic syndrome group ambulated at a slower average cadence throughout the entire day ($p = 0.012$), and at slower cadences for continuous durations of 60 minutes ($p = 0.006$), 30 minutes ($p = 0.005$), 20 minutes ($p = 0.003$), 5 minutes ($p = 0.002$), and 1 minute ($p = 0.001$). The metabolic syndrome group also had a slower discontinuous ambulatory cadence as measured by the peak ambulatory index ($p = 0.003$). The metabolic syndrome group took fewer strides per day ($p < 0.001$) than the controls, translating to more than 2,000 fewer steps per day (8,152 and 10,282 steps/day in the metabolic syndrome and control groups, respectively).

To assess which metabolic syndrome components, demographic measures, and body composition measures are associated with daily ambulatory cadence, we selected the daily average cadence for analyses because it provides an overall estimate of the rate of ambulation (Table 3). After adjustment for metabolic syndrome status, average cadence is linearly associated with age ($p < 0.001$), body fat percentage ($p < 0.001$), fat mass ($p < 0.01$), fat free mass ($p < 0.05$), and sex ($p < 0.05$). The linear association between daily average cadence and body fat percentage in subjects with and without metabolic syndrome is shown in Figure 1. Average cadence remained significantly lower for the metabolic syndrome group after adjusting for age ($p = 0.013$), height ($p = 0.008$), weight ($p = 0.024$), waist/hip ratio ($p = 0.004$), fat free mass ($p = 0.002$), sex ($p = 0.015$), race ($p = 0.025$), and elevated blood pressure ($p = 0.005$). Average cadence was no longer significantly different between the two groups after adjusting for body mass index ($p = 0.155$), body fat percentage ($p = 0.683$), fat mass ($p = 0.973$), elevated fasting glucose ($p = 0.296$), elevated triglycerides ($p = 0.245$), and reduced HDL cholesterol ($p = 0.088$).

In contrast to average cadence, which is a measure of the rate of walking, the number of strides taken per day, is a measure of ambulatory volume. Thus, the associations between daily ambulatory strides and metabolic syndrome components, demographic measures, and body composition measures are depicted in Table 4. After adjustment for metabolic syndrome status, daily ambulatory strides is linearly associated with body fat percentage ($p < 0.05$), fat mass ($p < 0.05$), and reduced HDL cholesterol ($p < 0.05$). Daily ambulatory strides remained significantly lower for the metabolic syndrome group after adjusting for age ($p = 0.001$), height ($p = 0.002$), waist/hip ratio ($p = 0.001$), fat free mass ($p = 0.009$), sex ($p = 0.001$), race ($p = 0.003$), elevated blood pressure ($p = 0.001$), and elevated triglycerides ($p = 0.006$). Daily ambulatory strides was no longer significantly different between the two groups after adjusting for body mass index ($p = 0.091$), body fat percentage ($p = 0.225$), fat mass ($p = 0.497$), elevated fasting glucose ($p = 0.060$), and reduced HDL cholesterol ($p = 0.069$).

DISCUSSION

Metabolic Syndrome and Daily Ambulatory Activity

A novel finding in this study is that ambulatory cadences of continuous durations ranging from one minute to one hour were slower in children, adolescents, and young adults with metabolic syndrome than those without metabolic syndrome. Furthermore, the metabolic syndrome group also had slower discontinuous ambulatory cadence, as measured by the peak ambulatory index, and they took fewer ambulatory strides each day. However, the daily amount of time spent ambulating was not different between subjects with and without metabolic syndrome. According to recent normative data and recommendations, both the metabolic syndrome group and the control group fall below the expected range of 11,000 to 15,000 steps per day in children, and 10,000 to 11,700 steps per day in adolescents.(38) Given that the daily average cadence of the metabolic syndrome group is 13.6 strides per minute (27.2 steps per minute), those with metabolic syndrome would need to ambulate for an average of nearly two additional hours per day to achieve 11,000 steps per day. In the best case scenario, if they were to ambulate at a cadence associated with their fastest daily minute (51.2 strides per minute, or 102.4 steps per minute), the metabolic syndrome group would need to ambulate for an additional 30 minutes per day to achieve 11,000 steps per day.

Our data suggest that children, adolescents, and young adults with metabolic syndrome engage in similar durations of ambulatory activities throughout each day compared to controls, but they do so at slower paces. The lower intensity of ambulation in the metabolic syndrome group should result in lower daily energy expenditure of physical activity, thereby favoring long-term positive energy balance, and exacerbating their greater body weight and fatness even further. Our results support the findings that the odds of having a cluster of risk factors increases with descending quartiles(4) and quintiles(2) of physical activity assessed by accelerometers. Collectively, these findings and our results support the notion that intensity of physical activity is an important factor in distinguishing between those with and without metabolic syndrome. This is further supported by studies showing that cardiorespiratory fitness is protective against developing metabolic syndrome in children and adolescents.(1, 3, 4) It is not surprising that the association between daily physical activity and metabolic syndrome is much weaker in studies quantifying activity with questionnaires,(22, 32) as self-reported moderate-to-vigorous physical activity is over-estimated by nearly 30 minutes per day, with the greatest errors found in the most inactive subjects.(26)

Components of Metabolic Syndrome and Daily Ambulatory Activity

Another key finding in this investigation is that body fatness, adjusted for metabolic syndrome status, is the most important determinant of daily ambulation in children, adolescents, and young adults. Daily ambulatory activity can be quantified in different aspects, consisting of the rate of walking (cadence), the duration of walking, and the number of strides taken while walking. We had a number of cadence measures to choose from to evaluate the association between the rate of walking with metabolic syndrome components, demographic measures, and body composition measures, and we selected the average cadence because it provides an overall estimate of the rate of daily ambulation. Body fat percentage and fat mass were both significantly and negatively associated with average cadence and daily ambulatory strides. Furthermore, the difference in ambulatory cadence and daily ambulatory strides between subjects with and without metabolic syndrome was no longer significant after adjusting for body fat percentage and fat mass. These results indicate that subjects with high levels of body fat ambulate at a slower pace and take fewer strides than those with less body fat, and that the lower ambulatory measures in those with

metabolic syndrome is primarily due to their greater body fatness. Our findings agree with others that found a strong association between obesity and objectively measured physical activity with either a pedometer(10) or an accelerometer.(9, 29, 35)

Age, Sex, and Daily Ambulatory Activity

It is important to note that both age and sex, adjusted for metabolic syndrome status, are associated with ambulatory cadence but not with daily ambulatory strides in children, adolescents, and young adults. However, the difference in ambulatory cadence between subjects with and without metabolic syndrome remained after adjusting for age and sex. These results indicate that ambulatory cadence is slowest in children and linearly increases up to age 30, males ambulate faster than females across this age range, and neither age nor sex eliminate the difference in ambulatory cadence between those with and without metabolic syndrome. The interpretation is that even though age and sex were associated with ambulatory cadence, the metabolic syndrome groups were not different on age or sex, and therefore adjustment of these variables has minimal effect on the group difference for ambulatory cadence. For the measure of daily ambulatory strides, our finding that age and sex are not associated with strides per day disagrees with a recent review which reports a decline in steps per day from childhood through adolescence, and that boys take more steps than girls.(38) The reason for this discrepancy is not clear, but our data suggests that average cadence is more closely related to demographic characteristics, such as age and sex, than is daily ambulatory strides.

Limitations

There are limitations to this study. The cross-sectional research design of this study does not allow causality to be established when examining the relationship between daily ambulatory activity and metabolic syndrome, the components of metabolic syndrome, demographic measures, and body composition. Thus, it is possible that metabolic syndrome slows ambulation, or that subjects who ambulate slowly are more likely to develop metabolic syndrome and the component of metabolic syndrome. A self-selection bias may also exist regarding study participation. Although we directly measured ambulatory activity, there are limitations associated with the step activity monitor. It is possible that the patients did not wear the step activity monitor during portions of their waking hours, thereby resulting in an underestimate of daily ambulation. We believe this possibility is unlikely because long durations in which no active minutes were recorded during daytime hours were rarely evident from the software graphs. Three subjects in the control group and one subject in the metabolic syndrome group had one day with zero steps recorded until late afternoon. In these cases, each of the four days were excluded from the monitoring period, and the subjects were asked to wear the monitor for an additional day to ensure seven days of activity monitoring. Another limitation is that the step activity monitor does not quantify non-ambulatory physical activity, and therefore it underestimates the total amount of daily physical activity accomplished to some extent. However, we believe non-ambulatory activity had minimal impact on the study results because ambulation is a large component of daily activity, and very few subjects indicated during the medical history that they were actively engaged in any type of non-ambulatory or resistance training exercise. There is a limitation associated with the assessment of body fat percentage, as bio-electrical impedance analysis technique underestimates fat mass and body fat percentage compared to dual-energy X-ray absorptiometry,(28, 34) even though the measures from both techniques are highly correlated.(31) A final limitation is that the present findings only apply to apparently healthy subjects with a wide range in body composition.

Summary, Conclusion, Clinical Significance

In summary, 18% of the subjects in the current study have metabolic syndrome as defined by the International Diabetes Federation, which far exceeds a previously reported prevalence of 3% to 4% in children and adolescents,(6) and 6.7% prevalence in adults between 20 and 29 years of age.(12) Children, adolescents, and young adults with metabolic syndrome have slower cadences during continuous ambulation ranging from one minute to one hour, discontinuous ambulation for 30 minutes, and total ambulation averaged for the entire day than those without metabolic syndrome. Furthermore, body fat percentage and fat mass were the primary factors associated with daily ambulatory activity, particularly with the cadence of ambulation.

In conclusion, children, adolescents, and young adults with metabolic syndrome ambulate more slowly and take fewer strides throughout the day than those without metabolic syndrome, even though the total amount of time spent ambulating is not different. Furthermore, the detrimental influence of metabolic syndrome on ambulatory cadence is primarily a function of body fatness. The clinical significance is that children, adolescents, and young adults with metabolic syndrome should be encouraged to ambulate at cadences slightly faster than their preferred pace and for at least 30 additional minutes throughout the course of a day as a simple means to potentially reduce body fatness and improve glucose, triglyceride, and HDL cholesterol profiles.

Acknowledgments

This research was supported by the National Center on Minority Health and Health Disparities (P20-MD-000528-05), and by the University of Oklahoma Health Sciences Center General Clinical Research Center grant (M01-RR-14467), sponsored by the National Center for Research Resources from the National Institutes of Health. The authors declare no conflict of interest in the study.

REFERENCES

1. Andersen LB, Hasselstrom H, Gronfeldt V, Hansen SE, Karsten F. The relationship between physical fitness and clustered risk, and tracking of clustered risk from adolescence to young adulthood: eight years follow-up in the Danish Youth and Sport Study. *Int J Behav Nutr Phys Act*. 2004; 1(1):6. [PubMed: 15169561]
2. Andersen LB, Harro M, Sardinha LB, et al. Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study). *Lancet*. 2006; 368(9532):299–304. [PubMed: 16860699]
3. Anderssen SA, Cooper AR, Riddoch C, et al. Low cardiorespiratory fitness is a strong predictor for clustering of cardiovascular disease risk factors in children independent of country, age and sex. *Eur J Cardiovasc Prev Rehabil*. 2007; 14(4):526–531. [PubMed: 17667643]
4. Brage S, Wedderkopp N, Ekelund U, et al. Features of the metabolic syndrome are associated with objectively measured physical activity and fitness in Danish children: the European Youth Heart Study (EYHS). *Diabetes Care*. 2004; 27(9):2141–2148. [PubMed: 15333475]
5. Chalmers LJ, Copeland KC, Hester CN, Fields DA, Gardner AW. Paradoxical increase in arterial compliance in obese pubertal children. *Angiology*. 2011; 62(7):565–570. [PubMed: 21421629]
6. Cruz ML, Goran MI. The metabolic syndrome in children and adolescents. *Curr Diab Rep*. 2004; 4(1):53–62. [PubMed: 14764281]
7. D'Adamo E, Santoro N, Caprio S. Metabolic syndrome in pediatrics: old concepts revised, new concepts discussed. *Endocrinol Metab Clin North Am*. 2009; 38(3):549–563. [PubMed: 19717004]
8. Dekker JM, Girman C, Rhodes T, et al. Metabolic syndrome and 10-year cardiovascular disease risk in the Hoorn Study. *Circulation*. 2005; 112(5):666–673. [PubMed: 16061755]
9. Dencker M, Thorsson O, Karlsson MK, et al. Daily physical activity related to body fat in children aged 8–11 years. *J Pediatr*. 2006; 149(1):38–42. [PubMed: 16860124]

10. Eisenmann JC, Laurson KR, Wickel EE, Gentile D, Walsh D. Utility of pedometer step recommendations for predicting overweight in children. *Int J Obes (Lond)*. 2007; 31(7):1179–1182. [PubMed: 17264846]
11. Fernandez JR, Redden DT, Pietrobelli A, Allison DB. Waist circumference percentiles in nationally representative samples of African-American, European-American, and Mexican-American children and adolescents. *J Pediatr*. 2004; 145(4):439–444. [PubMed: 15480363]
12. Ford ES, Giles WH, Dietz WH. Prevalence of the metabolic syndrome among US adults: findings from the third National Health and Nutrition Examination Survey. *JAMA*. 2002; 287(3):356–359. [PubMed: 11790215]
13. Ford ES, Li C, Zhao G. Prevalence and correlates of metabolic syndrome based on a harmonious definition among adults in the US. *J Diabetes*. 2010; 2(3):180–193. [PubMed: 20923483]
14. Garber CE, Blissmer B, Deschenes MR, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc*. 2011; 43(7):1334–1359. [PubMed: 21694556]
15. Gardner AW, Montgomery PS, Scott KJ, Afaq A, Blevins SM. Patterns of ambulatory activity in subjects with and without intermittent claudication. *J Vasc.Surg*. 2007; 46(6):1208–1214. [PubMed: 17919876]
16. Gardner AW, Parker DE. Association between arterial compliance and age in participants 9 to 77 years old. *Angiology*. 2010; 61(1):37–41. [PubMed: 19638351]
17. Gardner AW, Parker DE. Predictors of Large and Small Artery Elasticity in Healthy Subjects From 9 to 89 Years Old. *Am J Hypertens*. 2011
18. Hanson RL, Imperatore G, Bennett PH, Knowler WC. Components of the "metabolic syndrome" and incidence of type 2 diabetes. *Diabetes*. 2002; 51(10):3120–3127. [PubMed: 12351457]
19. Haskell WL, Lee IM, Pate RR, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Circulation*. 2007; 116(9):1081–1093. [PubMed: 17671237]
20. Isomaa B, Almgren P, Tuomi T, et al. Cardiovascular morbidity and mortality associated with the metabolic syndrome. *Diabetes Care*. 2001; 24(4):683–689. [PubMed: 11315831]
21. Janssen I, Leblanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *Int J Behav Nutr Phys Act*. 2010; 740
22. Kelishadi R, Razaghi EM, Gouya MM, et al. Association of physical activity and the metabolic syndrome in children and adolescents: CASPIAN Study. *Horm Res*. 2007; 67(1):46–52. [PubMed: 17035710]
23. Kesaniemi YK, Danforth E Jr, Jensen MD, Kopelman PG, Lefebvre P, Reeder BA. Dose-response issues concerning physical activity and health: an evidence-based symposium. *Med Sci Sports Exerc*. 2001; 33(6 Suppl):S351–S358. [PubMed: 11427759]
24. Laaksonen DE, Lakka HM, Niskanen LK, Kaplan GA, Salonen JT, Lakka TA. Metabolic syndrome and development of diabetes mellitus: application and validation of recently suggested definitions of the metabolic syndrome in a prospective cohort study. *Am J Epidemiol*. 2002; 156(11):1070–1077. [PubMed: 12446265]
25. Lakka HM, Laaksonen DE, Lakka TA, et al. The metabolic syndrome and total and cardiovascular disease mortality in middle-aged men. *JAMA*. 2002; 288(21):2709–2716. [PubMed: 12460094]
26. LeBlanc AG, Janssen I. Difference between self-reported and accelerometer measured moderate-to-vigorous physical activity in youth. *Pediatr Exerc Sci*. 2010; 22(4):523–534. [PubMed: 21242602]
27. McDonald CM, Widman L, Abresch RT, Walsh SA, Walsh DD. Utility of a step activity monitor for the measurement of daily ambulatory activity in children. *Arch Phys Med Rehabil*. 2005; 86(4):793–801. [PubMed: 15827934]
28. Neovius M, Hemmingsson E, Freyschuss B, Udden J. Bioelectrical impedance underestimates total and truncal fatness in abdominally obese women. *Obesity (Silver Spring)*. 2006; 14(10):1731–1738. [PubMed: 17062802]
29. Ness AR, Leary SD, Mattocks C, et al. Objectively measured physical activity and fat mass in a large cohort of children. *PLoS Med*. 2007; 4(3):e97. [PubMed: 17388663]

30. Ogden CL, Flegal KM, Carroll MD, Johnson CL. Prevalence and trends in overweight among US children and adolescents, 1999–2000. *JAMA*. 2002; 288(14):1728–1732. [PubMed: 12365956]
31. Pietrobelli A, Rubiano F, St-Onge MP, Heymsfield SB. New bioimpedance analysis system: improved phenotyping with whole-body analysis. *Eur J Clin Nutr*. 2004; 58(11):1479–1484. [PubMed: 15138459]
32. Ramirez-Lopez G, Gonzalez-Villalpando C, Sanchez-Corona J, et al. Weight, physical activity, and smoking as determinants of insulinemia in adolescents. *Arch Med Res*. 2001; 32(3):208–213. [PubMed: 11395186]
33. Slentz CA, Aiken LB, Houmard JA, et al. Inactivity, exercise, and visceral fat. STRRIDE: a randomized, controlled study of exercise intensity and amount. *J Appl Physiol*. 2005; 99(4):1613–1618. [PubMed: 16002776]
34. Sluyter JD, Schaaf D, Scragg RK, Plank LD. Prediction of fatness by standing 8-electrode bioimpedance: a multiethnic adolescent population. *Obesity (Silver Spring)*. 2010; 18(1):183–189. [PubMed: 19498351]
35. Stevens J, Murray DM, Baggett CD, et al. Objectively assessed associations between physical activity and body composition in middle-school girls: the Trial of Activity for Adolescent Girls. *Am J Epidemiol*. 2007; 166(11):1298–1305. [PubMed: 17855391]
36. Taylor RW, Jones IE, Williams SM, Goulding A. Evaluation of waist circumference, waist-to-hip ratio, and the conicity index as screening tools for high trunk fat mass, as measured by dual-energy X-ray absorptiometry, in children aged 3–19 y. *Am J Clin Nutr*. 2000; 72(2):490–495. [PubMed: 10919946]
37. Tremblay MS, Warburton DE, Janssen I, et al. New Canadian physical activity guidelines. *Appl Physiol Nutr Metab*. 2011; 36(1):36–46. 7–58. [PubMed: 21326376]
38. Tudor-Locke C, Craig CL, Beets MW, et al. How many steps/day are enough? for children and adolescents. *Int J Behav Nutr Phys Act*. 2011; 878
39. Zimmet P, Alberti KG, Kaufman F, et al. The metabolic syndrome in children and adolescents - an IDF consensus report. *Pediatr Diabetes*. 2007; 8(5):299–306. [PubMed: 17850473]

Figure 1. Daily average cadence versus body fat percentage in subjects with and without metabolic syndrome.

Table 1

Clinical characteristics of subjects with and without metabolic syndrome. Values are either means (standard deviation) or percentages.

Variables	Control Group (n = 205)	Metabolic Syndrome Group (n = 45)	P Value
Age (years)	17.9 (5.5)	17.2 (5.5)	0.437
Weight (kg)	66.3 (19.1)	105.7 (22.7)	< 0.001
Height (cm)	165.8 (11.8)	168.9 (9.1)	0.096
Body Mass Index (kg/m ²)	23.8 (5.3)	37.1 (7.7)	< 0.001
Waist / Hip Ratio	0.81 (0.07)	0.88 (0.08)	< 0.001
Body Fat Percentage (%)	25.1 (9.2)	40.8 (5.4)	< 0.001
Fat Mass (kg)	17.2 (10.3)	41.2 (10.3)	< 0.001
Fat Free Mass (kg)	47.8 (12.8)	59.2 (12.8)	< 0.001
Sex (% males)	51	44	0.445
Race (% Caucasian)	51	36	0.072
Abdominal Obesity (% yes)	25	100	< 0.001
Elevated Fasting Glucose (% yes)	12	82	< 0.001
Elevated Blood Pressure (% yes)	10	27	0.002
Elevated triglycerides (% yes)	4	80	< 0.001
Reduced HDL Cholesterol (% yes)	22	71	< 0.001

Table 2

Ambulatory activity of subjects with and without metabolic syndrome. Values are means (SD).

Variables	Control Group (n = 205)	Metabolic Syndrome Group(n = 45)	P Value
Ambulatory Strides (strides/day)	5141 (1898)	4076 (1679)	0.001
Ambulatory Time (min/day)	337 (102)	306 (102)	0.077
Average Cadence (strides/min)	14.9 (3.2)	13.6 (2.2)	0.012
Maximum 1-minute cadence (strides/min)	55.0 (6.3)	51.2 (6.6)	0.001
Maximum 5-minute cadence (strides/min)	43.7 (8.1)	39.4 (7.8)	0.002
Maximum 20-minute cadence (strides/min)	28.9 (8.7)	24.6 (6.6)	0.003
Maximum 30-minute cadence (strides/min)	25.0 (8.5)	21.0 (5.9)	0.005
Maximum 60-minute cadence (strides/min)	18.8 (7.2)	15.5 (4.8)	0.006
Peak Ambulatory Index (strides/min)	40.5 (8.4)	36.2 (7.9)	0.003

Table 3

Association between daily average cadence and covariates, controlled for metabolic syndrome status, and comparison of average cadence in subjects with and without metabolic syndrome after adjustment for each covariate.

Covariates	Slope	Partial R ²	Control Group Average Cadence Adjusted Mean (n = 205)	Metabolic Syndrome Group Average Cadence Adjusted Mean (n = 45)	P Value
Age	0.1342 ***	0.061	14.9	13.7	0.013
Height	0.0265	0.010	14.9	13.5	0.008
Weight	0.0044	0.001	15.0	13.5	0.024
Body Mass Index	-0.0236	0.002	14.9	13.9	0.155
Waist / Hip Ratio	4.4051	0.012	15.0	13.4	0.004
Body Fat Percentage	-0.0852 ***	0.086	14.3	14.6	0.683
Fat Mass	-0.0479 **	0.038	14.4	14.4	0.973
Fat Free Mass	0.0305 *	0.024	14.7	13.2	0.002
Male Sex †	0.7819 *	0.017	14.9	13.6	0.015
Caucasian Race †	0.4631	0.006	15.0	13.7	0.025
Elevated Fasting Glucose †	-0.8434	0.008	14.8	14.1	0.296
Elevated Blood Pressure †	0.8830	0.010	15.0	13.5	0.005
Elevated triglycerides †	-0.4551	0.001	14.8	13.9	0.245
Reduced HDL Cholesterol †	-0.7826	0.012	14.8	13.9	0.088

* Significant linear regression ($p < 0.05$),

** ($p < 0.01$),

*** ($p < 0.001$).

† Referent groups are females, non-Caucasians, and absence of elevated fasting glucose, elevated blood pressure, elevated triglycerides, and reduced HDL cholesterol.

Table 4

Association between daily ambulatory strides and covariates, controlled for metabolic syndrome status, and comparison of ambulatory strides in subjects with and without metabolic syndrome after adjustment for each covariate.

Covariates	Slope	Partial R ²	Control Group Daily Strides Adjusted Mean (n = 205)	Metabolic Syndrome Group Daily Strides Adjusted Mean (n = 45)	P Value
Age	24.81	0.005	5139	4085	0.001
Height	-13.42	0.007	5122	4109	0.002
Weight	-7.03	0.006	5091	4311	0.056
Body Mass Index	-23.50	0.005	5072	4341	0.091
Waist / Hip Ratio	1231.85	0.003	5193	4006	0.001
Body Fat Percentage	-33.34 *	0.026	4911	4431	0.225
Fat Mass	-29.53 *	0.028	4877	4582	0.497
Fat Free Mass	-8.16	0.003	4989	4072	0.009
Male Sex †	423.61	0.013	5137	4097	0.001
Caucasian Race †	260.69	0.005	5191	4213	0.003
Elevated Fasting Glucose †	-351.55	0.004	5079	4282	0.060
Elevated Blood Pressure †	52.86	0.000	5143	4068	0.001
Elevated triglycerides †	631.09	0.006	5205	3775	0.006
Reduced HDL Cholesterol †	-682.94 *	0.024	5067	4442	0.069

* Significant linear regression ($p < 0.05$).

† Referent groups are females, non-Caucasians, and absence of elevated fasting glucose, elevated blood pressure, elevated triglycerides, and reduced HDL cholesterol.