JOMH
Journal of Men's Health

Original Article
DOI: 10.22374/jomh.v15i3.152

ASSOCIATION OF FITNESS, BODY CIRCUMFERENCE, MUSCLE MASS, AND EXERCISE HABITS WITH METABOLIC SYNDROME

Kyu Kwon Cho, PhD[1], Young Hak Kim, MD, PhD[2], Yong Hwan Kim, PhD[1]

[1]Department of Physical Education, Gangneung-Wonju National University, Gangneung-si, Republic of Korea

[2]Department of Cardiology, Seoul Asan Medical Center, Seoul, Republic of Korea

Corresponding Authors: Yong Hwan Kim: yhkim@gwnu.ac.kr, Young Hak Kim: mdyhkim@amc.seoul.kr

Submitted: 13 June 2019. Accepted: 06 August 2019. Published: 04 September 2019.

ABSTRACT

Background and objective

Metabolic syndrome (MetS) can be improved by diet, cessation of smoking, and in particular exercise. The purpose of this study was to analyze the association of exercise-related factors such as fitness, exercise habits, muscle, and body fat with MetS.

Methods

Data were collected for research purposes from 398 males aged 40–50 years. Appendicular skeletal muscle mass (ASM) and body fat percentage were analyzed using bioelectrical impedance analysis (BIA). Fitness was evaluated using cardiopulmonary fitness, grip strength, and leg power. Exercise habits included exercise frequency, intensity, and duration. Data were analyzed using the odds ratio (OR), calculated by logistic regression analysis.

Results

There was no significant difference in age between the non-MetS (51.1 years) and the MetS (51.5 years) groups. Differences in dyslipidemia and fitness variables classified as MetS risk factors were significant between groups. The group with the highest cardiopulmonary fitness had an OR of 0.426 (95% confidence interval [CI], 0.191–0.948) when compared with the lowest group, while grip strength was not significantly different. Obesity factors such as body fat percentage, body mass index, and waist circumference were significantly prevalent. The group with the largest thigh circumference had an OR of 0.299 (95% CI, 0.101–0.881) when compared to the group with the smallest thigh circumference. Calf circumference did not yield significant results. The group with the highest ASM had an OR of 0.346

when compared with the lowest group. Higher exercise frequency and longer duration were associated with a lower prevalence of MetS.

Conclusion

Among physical strength, circumference, muscle mass, and obesity factors, MetS was most affected by obesity factors. Furthermore, higher cardiopulmonary fitness and frequent exercise can be helpful for MetS prevention.

Key Words: *exercise behavior; fitness; metabolic syndrome; muscle; obesity*

INTRODUCTION

Metabolic syndrome (MetS) refers to the clustering of hypertension, diabetes, obesity, and dyslipidemia. While each disease is not a pathologic diagnosis, each can be categorized as an MetS disease if several other risk factors are present.[1] Previous studies have shown that individuals with MetS are more likely to develop cardiovascular disease over the decade following diagnosis.[2] In developed countries, cardiovascular disease is the most common cause of death, with sudden death and stroke particularly impacting the quality of life of individuals and families. Prevention efforts have positive impact on quality of life in these populations and reduce overall disease burden.[3] MetS is considered a Lifestyle Disease, which is routinely managed with weight control, cessation of smoking, reduced alcohol consumption, limited calorie intake, a balanced diet, and regular exercise.[4] Many studies have reported the positive effect of increased physical activity on MetS, including resolution of obesity, decreased blood pressure and blood glucose, and increased high-density lipoprotein (HDL) cholesterol.[5]

In particular, increased waist circumference, a marker of abdominal obesity, is a significant risk factor for MetS. Increased calf and thigh circumference, which reflect muscle mass, have been reported to have a positive effect on cardiovascular disease and risk factors.[6–8] Muscle mass can also be easily measured by bioelectrical impedance analysis (BIA).[9] Questionnaires covering exercise habits can assess the frequency, intensity, and duration of physical activity, but lack quantitative measurements to assess physical activity in daily living.[10] In recent years, Internet of things (IoT) devices have allowed information on exercise and physical activity to be quantified and obtained electronically and have been used to demonstrate positive correlations between greater physical activity and improved overall health.[11,12]

While low-intensity exercise is effective in the prevention of chronic diseases,[13,14] studies suggest that high-intensity exercise is more effective in improving blood pressure and triglyceride levels compared with low-intensity exercise.[15,16] Accordingly, the principle of overloading, or modifying exercise as fitness improves, should be considered and applied to improve and maintain fitness as a part of overall physical health.[17] Therefore, this study aimed to analyze the association of exercise-related factors such as fitness, exercise habits, muscle, and fat with MetS.

METHODS

Subjects and Procedure

A total of 398 male patients were included in this study. Data on blood pressure, body composition, body size measurements, and fitness were collected. Questionnaires for past medical history and exercise habits were completed before the medical tests, and information for those providing consent was included in the study. Participants who did not fit age and gender requirements or did not consent to participate were excluded.

Participants were instructed to fast for at least 8 h prior to testing and were prohibited from consuming food except for small amounts of water. Blood pressure and lipid profiling were performed after the first measurement of height, weight, waist, and calf and thigh circumferences to minimize the influence of mutual interference. Patients were checked for overall health after testing and then discharged.

Metabolic Syndrome

The MetS diagnosis was based on the National Cholesterol Education Program-Adult Treatment Panel III (NCEP-ATP III) criteria, and waist circumference analysis was based on the WHO-Asian standard of ≥90 cm.[18,19] MetS was diagnosed when three or more of the following five items were present: triglycerides ≥150 mg/dL, HDL-C <40 mg/dL, blood pressure ≥130/85 mmHg, fasting blood glucose ≥100 mg/dL, and waist circumference ≥90 cm. Medication used to regulate triglycerides or blood pressure was considered as a diagnosis.

Fitness Test

Cardiopulmonary fitness (VO_2max)

Maximal volume uptake (VO_2max) was measured using a treadmill and gas analyzer (Vmax229; Sensormedics Co. Ltd, USA). Maximal examinations were performed unless there were clinical complications. Heart rate, electrocardiograms (ECG), rating of perceived exertion (RPE) using the Borg scale,[20] and VO_2 were monitored to check for abnormalities. Data that failed to reach the maximum capacity, such as ECG abnormalities, musculoskeletal problems, and discontinuation at RPE 15 or less, were excluded from the analysis.

Grip strength and vertical jump

Grip strength was measured using a Takei 5401 grip dynamometer (Takei Co. Ltd, Japan). For each participant, feet were positioned at shoulder width, the device was adjusted to fit the hand for maximum strength, and the arm and elbow were straightened. Maximum strength was generated in accordance with the "start" signal of the inspector and maintained for approximately 2 s. The test was performed twice, and the maximum value was recorded in kilogram. The TKK 5406 vertical jump meter (Takei Co. Ltd, Japan) was used to measure the maximum vertical jump. After two measurements, the highest value was recorded in centimeter.

Body Composition

To measure body composition, BIA was performed using the Inbody770 (Biospace Co., Seoul, Korea). Body fat and ASM were measured and analyzed with absolute value and relative value (absolute value/body weight).

Circumference

Circumference measurements for waist, thigh, and calf were performed twice using American College of Sports Medicine (ACSM) guidelines.[21] If the difference between the two measurements was <0.5 cm, the higher value was recorded; if the difference was >0.5 cm, remeasurement was performed.

Measurements were taken on the right side of each participant with the tape measure kept horizontal. The circumference of the thigh was measured at the maximum perimeter just below the hip with the feet slightly open. Calf circumference was measured halfway between the knee and ankle with the feet slightly open. Waist circumference was measured at the navel line.

Exercise Habit Questionnaire

Participants completed a questionnaire to assess exercise frequency per week, intensity, and average duration. Exercise frequency was categorized as none, 1–2, 3–5, and 6–7 days. Exercise time was categorized as <20, 20–60, and >60 min. Exercise intensity using the Borg scale RPE was 9, 11, 13, and ≥15.[20]

Statistical Analysis

Statistical analyses were performed using SPSS 21.0 (IBM SPSS Inc., USA). Continuous variables were recorded as means±standard deviation, and categorical variables related to exercise habit were recorded as percentages. The independent *t*-test was used for continuous variables and non-MetS comparisons, and the chi-square test was used for categorical variables. To obtain age and weight adjusted odds ratios (ORs), continuous variables were grouped into quartiles. Logistic regression analysis was performed.

The fitness variable was divided into four groups by quartile, with G1 being the lowest, G2 low, G3 high, and G4 being the highest. These groups assigned to respective waist circumferences, body fat, and body mass index (BMI), with the highest measurements in G1 and lowest in G4. Factors used to determine muscle mass are listed in Table 4. Thigh and calf circumference and ASM percentage were lowest in G1 and highest in G4. Analysis of exercise habits categorized participants with low frequency, duration, and intensity into G1 and high frequency, duration, and intensity into G4. Values of $p<0.05$ were considered statistically significant.

RESULTS

General Characteristics

Seventy-seven participants (19.3%) were diagnosed with MetS. There was no significant

TABLE 1. Characteristics of Subjects

Variables	Non-MetS (n=321)	MetS (n=77)	p
Age (years)	51.1±4.8	51.5±5.0	0.559
Weight (kg)	70.5±8.8	78.1±7.1	<0.001*
Height (cm)	170.2±5.2	171.6±5.0	0.032
Obesity and muscle-related factors			
BMI (kg/m^2)	24.3±2.5	26.5±2.1	<0.001*
Waist circumference (cm)	85.2±6.9	92.5±5.3	<0.001*
Thigh circumference (cm)	53.6±3.9	55.2±3.4	<0.001*
Calf circumference (cm)	36.4±2.4	37.5±2.3	<0.001*
ASM (%)	77.1±3.7	74.2±3.6	<0.001*
Body fat ratio (%)	18.5±3.9	21.6±3.8	<0.001*
Cardiovascular risk factors			
SBP (mmHg)	119.4±9.7	128.0±11.3	<0.001*
DBP (mmHg)	77.5±8.1	84.2±9.1	<0.001*
Total cholesterol 9mg/dL)	195.9±31.2	199.4±38.5	0.411
HDL cholesterol (mg/dL)	52.5±11.7	44.7±11.4	<0.001*
LDL cholesterol (mg/dL)	122.3±28.4	122.5±32.9	0.948
Triglyceride (mg/dL)	131.7±75.9	221.5±115.4	<0.001*
Glucose (mg/dL)	101.6±20.3	121.4±32.7	<0.001*
Fitness			
VO_2max (mL/kg/min)	30.2±4.4	28.4±3.1	<0.001*
Vertical jump (cm)	36.7±4.9	34.2±5.4	<0.001*
Grip strength (kg)	41.5±6.2	40.7±5.5	0.303

ASM, appendicular skeletal muscle mass; BMI, body mass index; DBP, diastolic blood pressure; HDL, high-density lipoprotein; LDL, low-density lipoprotein; SBP, systolic blood pressure.
**p<0.05.*

difference (p=0.559) in age between non-MetS (51.1±4.8 years) and MetS (51.5±5.0 years). Body fat percentage was significantly higher in the MetS group ($p<0.05$). There was no significant difference in total or LDL cholesterol. Physical strength was similar between the groups (41.5±6.2 vs. 40.7±5.5, p=0.303). Cardiopulmonary fitness was significantly higher ($p<0.001$) in the non-MetS group (30.2 mL/kg/min) compared with the MetS group (28.4 mL/kg/min) (Table 1).

MetS Odds Ratio and Fitness Factors

Fitness was measured by cardiopulmonary fitness, vertical jump, and grip strength (Table 2). For cardiopulmonary fitness, the OR was lower in G4 (OR 0.426, 95% confidence interval [CI], 0.191–0.948) than G1. For vertical jump, the ORs of G3 and G4 were 0.394 (95% CI, 0.181–0.857) and 0.312 (95% CI, 0.116–0.835) lower than G1, respectively. The grip strength was not significantly different between groups.

MetS Odds Ratio and Obesity Factors

Obesity factors include BMI and waist circumference and were included with body fat percentage as factors of MetS (Table 3). The ORs for waist circumference in G3 and G4 were 0.136 (95% CI, 0.042–0.300) and 0.112 (95% CI, 0.017–0.192) lower than G1, respectively. Body fat percentage was 68% lower in G4 compared with G1, and BMI OR was significantly decreased in G3 and G4 compared with G1.

MetS Odds Ratio and Muscle Factors

Muscle mass ratio and thigh and calf circumference measurements are listed in Table 4. These factors were adjusted for body weight to determine effects of circumference and muscle mass. The G4

TABLE 2. MetS Odds Ratio According to Fitness

	VO_2max			**Vertical Jump**			**Grip Strength**		
	mL/kg/min	**OR**	**95% CI**	**cm**	**OR**	**95% CI**	**kg**	**OR**	**95% CI**
G1	≤27.4	1	-	≤33.0	1	-	≤37.0	1	-
G2	≤28.6	0.678	0.333–1.382	≤36.0	0.995	0.499–1.984	≤41.1	1.351	0.645–2.831
G3	≤30.8	0.455	0.194–1.072	≤40.0	0.394	0.181–0.857*	≤45.1	0.778	0.347–1.744
G4	>30.8	0.426	0.191–0.948*	>40.0	0.312	0.116–0.835*	>45.1	0.550	0.240–1.263

CI, confidence interval; OR, odds ratio.
Adjusted factors were included age, fat %, ASM %, exercise, alcohol and smoking. And VO_2max, vertical jump and grip strength were adjusted respectively.
**p<0.05. Fitness-related factor classified by lowest G1, low G2, high G3, and highest G4.*

TABLE 3. MetS Odds Ratio According to Obesity Factors

	Waist Circumference			**Body Fat Percent**			**BMI**		
	cm	**OR**	**95% CI**	**%**	**OR**	**95% CI**	**kg/m²**	**OR**	**95% CI**
G1	≥91.0	1	-	≥21.5	1	-	≥26.3	1	
G2	≥87.0	0.063	0.309–1.177	≥19.0	1.281	0.660–2.485	≥24.7	0.449	0.233–0.864*
G3	≥82.0	0.136	0.042–0.300*	≥16.8	0.526	0.184–1.501	≥23.0	0.098	0.040–0.245*
G4	<82.0	0.112	0.017–0.192*	<16.8	0.321	0.124–0.833*	<23.0	0.074	0.027–0.209*

BMI, body mass index; CI, confidence interval; OR, odds ratio.
Adjusted factors were included age, VO_2max, vertical jump, grip strength, exercise, alcohol and smoking. And waist circumference, fat %, BMI were adjusted respectively.
**p<0.05. Obesity-related factor classified by highest G1, high G2, low G3, and lowest G4.*

TABLE 4. MetS Odds Ratio According to Body Muscle Factors

	Thigh Circumference			Calf Circumference			ASM Percent		
	cm	OR	95%CI	cm	OR	95%CI	%	OR	95%CI
G1	≤51.5	1	-	≤36.0	1	-	≤22.1	1	-
G2	≤54.3	0.486	0.181–1.304	≤36.5	1.322	0.498–3.506	≤24.2	0.747	0.409–1.365
G3	≤56.5	0.408	0.145–1.152	≤38.4	2.342	0.925–5.929	≤25.9	0.467	0.232–0.784*
G4	>56.5	0.299	0.101–0.881*	>38.4	1.664	0.648–4.272	>25.9	0.346	0.161–0.651*

ASM, appendicular skeletal muscle; CI, confidence interval; OR, odds ratio.
Adjusted factors were included age, VO_2max, vertical jump, grip strength, exercise, alcohol and smoking. And thigh circumference, calf circumference, ASM % were adjusted respectively.
**$p<0.05$. Muscle-related factor classified by lowest G1, low G2, high G3, and highest G4.*

TABLE 5. MetS Odds Ratio According to Exercise Habits

	Frequency			Duration			Intensity		
	ds/wk	OR	95% CI	min	OR	95% CI	RPE	OR	95% CI
G1	None	1	-	≤20	1	-	≤9	1	-
G2	1–2	0.327	0.085–1.254	20–60	0.740	0.349–1.568	10–11	1.160	0.394–3.415
G3	3–5	0.614	0.277–1.362	>60	0.503	0.275–0.920*	12–13	0.966	0.308–3.032
G4	6–7	0.468	0.215–0.917*	-	-	-	>15	0.544	0.086–3.427

ds/wk, days/week; CI, confidence interval; OR, odds ratio; RPE, rating of perceived exertion using Borg scale.
Adjusted factors were included age, VO_2max, vertical jump, grip strength, fat %, ASM %, exercise, alcohol and smoking. And exercise frequency, duration, intensity were adjusted respectively.
**$p<0.05$. Exercise habit-related factor classified by lowest G1, low G2, high G3, and highest G4.*

OR was 0.299 (95% CI 0.101–0.881) when compared with G1. Calf circumference was not significantly different between any groups. The OR of highest ASM group (G4) was 0.346 when comparing G1, in which the ASM was lowest.

MetS Odds Ratio and Exercise Habits

Exercise frequency was 54% higher in G4 than G1. The group that exercised for more than 60 min had an OR of 0.503 (95% CI, 0.275–0.920) when compared with the group that exercised 20 min or less. Exercise intensity did not yield significant results.

DISCUSSION

Several methods and factors should be considered when interpreting exercise and physical activity data. To quantify physical activity data, a questionnaire that measures duration, frequency, and intensity of exercise can be used. Recent advancements in technology allow physical activity to be measured by an activity monitoring device or smartphone app.[10,22] Other fitness parameters include cardiopulmonary fitness, strength, and exercise habits. The most studied areas are cardiopulmonary fitness and muscle strength, which report low disease prevalence with increased fitness.[23,24] Next are body fat and muscle mass as factors related to body composition. In this study, ASM was analyzed as muscle mass and body fat percentage. Muscle mass increases through muscle strengthening training or resistance exercise, while weight gain increases muscle and fat masses.[21,25] The most accurate measures of muscle mass are obtained by computed tomography (CT), magnetic resonance imaging (MRI), and dual-energy X-ray absorptiometry (DXA), but these have the disadvantage of high cost.[26] Therefore, we measured muscle and ASM with BIA in this study. One study used thigh circumference as a measure of sarcopenia, but this method has limitations in measuring pure muscle mass because it does not exclude fat.[27] The final factor to consider is obesity, traditionally measured by BMI, waist circumference, and waist-to-hip ratio. In addition, abdominal CT for measuring visceral fat, BIA body fat, and waist-to-height ratio have been used to classify obesity.[28,29] Body fat based on BIA, BMI, and waist circumference were analyzed in this study.

Most prior studies analyzed one or two variables related to fitness, exercise habits, obesity, and muscle mass, each of which showed significant results. Furthermore, some research focused on whether fitness or fatness is important. Although people are not obese or overweight, individuals with high physical fitness have mortality similar to those with normal weight.[23] Moreover, patients with high BMI had a higher risk of type 2 diabetes mellitus than those with normal BMI, regardless of physical activity levels, highlighting the importance of BMI.[30] That study also showed that increased physical strength had more influence on disease-related factors than high physical activity.[30] Our study analyzed additional measures of fitness, including leg power, cardiopulmonary endurance, and upper body strength. Studies on leg strength have been carried out using muscle strength rather than the vertical jump, and it has been reported that higher strength increases disease prevention effects.[31,32] Grip strength is the most widely used measure of upper limb muscle strength because it is safe, easy to measure, and was reported in many documents.[33–35] Most previous studies on health factors and grip strength reported that grip strength has marker for disease prevention and mortality, whereas our study did not.[34–37] These results are similar in the Katzmarzyk and Craig study.[38] They reported that mortality was not significantly related to grip strength, but suggested that cardiopulmonary fitness was related.[38] In this study, cardiopulmonary fitness and vertical jump were considered as covariates, and applied as correction factors with grip strength, but were not significant. It is possible that the reduction of grip strength was not remarkable because of the middle age of the participants in this study.

Commonly used anthropometric and BIA measurements were used for obesity and muscle mass-related factors. G2, G3, and G4 showed decreased OR when compared with G1 in BMI, which is a representative diagnostic method of obesity. This also supports the idea that waist circumference, which indicates abdominal obesity, is a risk factor for MetS.

The body fat percentage and muscle mass ratio measured using BIA showed that a lower body fat percent and higher ASM, the lower the MetS prevalence, and prevention of MetS increased proportionally to increases in muscle mass (Tables 3 and 4). Increases in body weight tended to be negative, but increased thigh circumference has been associated with decreased mortality.[7,27] Thigh circumference measurements do not require the use of expensive imaging equipment such as CT or MRI, and circumferential reduction is a simple method of predicting sarcopenia.[8,39] Hida et al. reported that the risk of vertebral fracture increases with decreasing lower leg muscle mass in patients with sarcopenia, highlighting the importance of preventing muscle mass loss.[40] Although not significant, OR 0.327 was the lowest of all exercise habits in Table 5. The low MetS prevalence in spite of low exercise is a different result from the general facts and should be considered in future study. Finally, prevention of MetS is related to exercise frequency. The ACSM guideline recommends high-intensity exercise at least 3 days per week or at least 5 days per week of moderate-intensity exercise.[21] Our results are consistent with prior research, showing that high-exercise frequency can prevent MetS. Previous studies have demonstrated that high-intensity exercise is more effective than low-intensity exercise.[41–43] However, exercise intensity is typically a subjective measure, making consistent results difficult to reproduce. We addressed this by measuring cardiopulmonary endurance by VO_2max, which is an accurate, objective measurement. Follow-up studies are needed to compare high-intensity/low-frequency versus low-intensity/high-frequency exercise to address these disparities.

There are several limitations associated with this study. Due to the cross-sectional analysis, it is limited in confirming muscle training effects and reduction of fat. Although all variables were divided into multiple groups, there is a limit in making direct comparisons. It may be relatively easy to improve cardiopulmonary fitness through training, but more difficult to increase the vertical jump. It is also difficult to normalize weight loss, which occurs at different rates in each individual. Finally, dietary status is also very important in terms of blood pressure, blood glucose, and obesity, which was not reflected in this study.

CONCLUSIONS

This study demonstrated that increased cardiopulmonary endurance and vertical jumping ability lower the prevalence of MetS. MetS was also associated with lower muscle mass, and the prevalence of MetS was significantly lower in those who exercise 6–7 days/week and for at least 60 min.

FUNDING

This study was supported by the 2019 Gangneung-Wonju National University research fund.

CONFLICT OF INTEREST

The authors report no conflicts of interest.

REFERENCES

1. Alberti KGM, Zimmet P, Shaw J. The metabolic syndrome—A new worldwide definition. Lancet 2005;366:1059–62. https://doi.org/10.1016/S0140-6736(05)67402-8
2. Mottillo S, Filion KB, Genest J, et al. The metabolic syndrome and cardiovascular risk: A systematic review and meta-analysis. J Am Coll Cardiol 2010;56:1113–32. https://doi.org/10.1016/j.jacc.2010.05.034
3. Malik S, Wong ND, Franklin SS, et al. Impact of the metabolic syndrome on mortality from coronary heart disease, cardiovascular disease, and all causes in United States adults. Circulation 2004;110:1245–50. https://doi.org/10.1161/01.CIR.0000140677.20606.0E
4. Wannamethee SG, Shaper AG, Whincup PH. Modifiable lifestyle factors and the metabolic syndrome in older men: Effects of lifestyle changes. J Am Geriatr Soc 2006;54:1909–14. https://doi.org/10.1111/j.1532-5415.2006.00974.x
5. Yamaoka K, Tango T. Effects of lifestyle modification on metabolic syndrome: A systematic review and meta-analysis. BMC Med 2012;10:138. https://doi.org/10.1186/1741-7015-10-138
6. Pouliot M-C, Després J-P, Lemieux S, et al. Waist circumference and abdominal sagittal diameter: Best simple anthropometric indexes of abdominal visceral adipose tissue accumulation and related cardiovascular risk in men and women. Am J Cardiol 1994;73:460–8. https://doi.org/10.1016/0002-9149(94)90676-9
7. Heitmann BL, Frederiksen P. Thigh circumference and risk of heart disease and premature death: Prospective cohort study. BMJ 2009;339:b3292. https://doi.org/10.1136/bmj.b3292
8. Ishii S, Tanaka T, Shibasaki K, et al. Development of a simple screening test for sarcopenia in older adults. Geriatr Gerontol Int 2014;14:93–101. https://doi.org/10.1111/ggi.12197
9. Atkins J, Whincup P, Morris R, et al. Low muscle mass in older men: The role of lifestyle, diet and cardiovascular risk factors. J Nutr Health Aging 2014;18:26–33. https://doi.org/10.1007/s12603-013-0336-9

10. Lee PH, Macfarlane DJ, Lam T, et al. Validity of the international physical activity questionnaire short form (IPAQ-SF): A systematic review. Int J Behav Nutr Phys Act 2011;8:115. https://doi.org/10.1186/1479-5868-8-115
11. De Bourdeaudhuij I, Maes L, De Henauw S, et al. Evaluation of a computer-tailored physical activity intervention in adolescents in six European countries: The Activ-O-Meter in the HELENA intervention study. J Adolesc Health 2010;46:458–66. https://doi.org/10.1016/j.jadohealth.2009.10.006
12. Bassett Jr DR, Wyatt HR, Thompson H, et al. Pedometer-measured physical activity and health behaviors in United States adults. Med Sci Sports Exerc 2010;42:1819. https://doi.org/10.1249/MSS.0b013e3181dc2e54
13. Archer E, Blair SN. Physical activity and the prevention of cardiovascular disease: From evolution to epidemiology. Prog Cardiovasc Dis 2011;53:387–96. https://doi.org/10.1016/j.pcad.2011.02.006
14. van Waart H, Stuiver MM, van Harten WH, et al. Effect of low-intensity physical activity and moderate-to high-intensity physical exercise during adjuvant chemotherapy on physical fitness, fatigue, and chemotherapy completion rates: Results of the PACES randomized clinical trial. J Clin Oncol 2015;33:1918–27. https://doi.org/10.1200/JCO.2014.59.1081
15. Paoli A, Pacelli QF, Moro T, et al. Effects of high-intensity circuit training, low-intensity circuit training and endurance training on blood pressure and lipoproteins in middle-aged overweight men. Lipids Health Dis 2013;12:131. https://doi.org/10.1186/1476-511X-12-131
16. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle. Sports Med 2013;43:313–38. https://doi.org/10.1007/s40279-013-0029-x
17. Stone MH, Collins D, Plisk S, et al. Training principles: Evaluation of modes and methods of resistance training. Strength Cond J 2000;22:65. https://doi.org/10.1519/1533-4295(2000)022<0065:TPEOMA>2.0.CO;2
18. Johnson KM, Dowe DA. Accuracy of statin assignment using the 2013 AHA/ACC Cholesterol Guideline versus the 2001 NCEP ATP III guideline: Correlation with atherosclerotic plaque imaging. J Am Coll Cardiol 2014;64:910–19. https://doi.org/10.1016/j.jacc.2014.05.056
19. WHO. Obesity: Preventing and managing the global epidemic. Report of the WHO consultation on obesity. Geneva: World Health Organization; 1998.
20. Wilson RC, Jones P. A comparison of the visual analogue scale and modified Borg scale for the measurement of dyspnoea during exercise. Clin Sci 1989;76:277–82. https://doi.org/10.1042/cs0760277
21. ACSM. ACSM's exercise testing and prescription. Philadelphia, PA: Lippincott Williams & Wilkins; 2017.
22. Sasaki JE, Hickey A, Mavilia M, et al. Validation of the Fitbit wireless activity tracker for prediction of energy expenditure. J Phys Act Health 2015;12:149–54. https://doi.org/10.1123/jpah.2012-0495
23. Barry VW, Baruth M, Beets MW, et al. Fitness vs. fatness on all-cause mortality: A meta-analysis. Prog Cardiovasc Dis 2014;56:382–90. https://doi.org/10.1016/j.pcad.2013.09.002
24. García-Hermoso A, Cavero-Redondo I, Ramírez-Vélez R, et al. Muscular strength as a predictor of all-cause mortality in apparently healthy population: A systematic review and meta-analysis of data from approximately 2 million men and women. Archiv Phys Med Rehabil 2018;99:2100–2113. https://doi.org/10.1016/j.apmr.2018.01.008
25. Arora NS, Rochester DF. Effect of body weight and muscularity on human diaphragm muscle mass, thickness, and area. J Appl Physiol 1982;52:64–70. https://doi.org/10.1152/jappl.1982.52.1.64
26. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, et al. Sarcopenia: European consensus on definition and diagnosisReport of the European Working Group on Sarcopenia in Older PeopleA. Age Ageing 2010;39:412–23. https://doi.org/10.1093/ageing/afq034
27. Snijder MB, Dekker JM, Visser M, et al. Larger thigh and hip circumferences are associated with better glucose tolerance: The Hoorn study. Obesity 2003;11:104–11. https://doi.org/10.1038/oby.2003.18

28. Ashwell M, Hsieh SD. Six reasons why the waist-to-height ratio is a rapid and effective global indicator for health risks of obesity and how its use could simplify the international public health message on obesity. Int J Food Sci Nutr 2005;56:303–7. https://doi.org/10.1080/09637480500195066
29. Yu O-K, Rhee Y-K, Park T-S, et al. Comparisons of obesity assessments in over-weight elementary students using anthropometry, BIA, CT and DEXA. Nutr Res Pract 2010;4:128–35. https://doi.org/10.4162/nrp.2010.4.2.128
30. Fogelholm M. Physical activity, fitness and fatness: Relations to mortality, morbidity and disease risk factors. A systematic review. Obes Rev 2010;11:202–21. https://doi.org/10.1111/j.1467-789X.2009.00653.x
31. Sayer AA, Syddall H, Dennison E, et al. Grip strength and the metabolic syndrome: Findings from the Hertfordshire Cohort Study. QJM 2007;100:707–13. https://doi.org/10.1093/qjmed/hcm095
32. Miyatake N, Wada J, Saito T, et al. Comparison of muscle strength between Japanese men with and without metabolic syndrome. Acta Med Okayama 2007;61:89–102.
33. Lim ECW. Pain free grip strength test. J Physiother 2013;59:59. https://doi.org/10.1016/S1836-9553(13)70152-8
34. Gale CR, Martyn CN, Cooper C, et al. Grip strength, body composition, and mortality. Int J Epidemiol 2006;36:228–35. https://doi.org/10.1093/ije/dyl224
35. Giampaoli S, Ferrucci L, Cecchi F, et al. Handgrip strength predicts incident disability in non-disabled older men. Age Ageing 1999;28:283–8. https://doi.org/10.1093/ageing/28.3.283
36. Ling CH, Taekema D, de Craen AJ, et al. Handgrip strength and mortality in the oldest old population: The Leiden 85-plus study. Can Med Assoc J 2010;182:429–35. https://doi.org/10.1503/cmaj.091278
37. Leong DP, Teo KK, Rangarajan S, et al. Prognostic value of grip strength: Findings from the Prospective Urban Rural Epidemiology (PURE) study. Lancet 2015;386:266–73. https://doi.org/10.1016/S0140-6736(14)62000-6
38. Katzmarzyk PT, Craig CL. Musculoskeletal fitness and risk of mortality. Med Sci Sports Exerc 2002;34:740–4. https://doi.org/10.1097/00005768-200205000-00002
39. Cooper C, Fielding R, Visser M, et al. Tools in the assessment of sarcopenia. Calcif Tissue Int 2013;93:201–10. https://doi.org/10.1007/s00223-013-9757-z
40. Hida T, Shimokata H, Sakai Y, et al. Sarcopenia and sarcopenic leg as potential risk factors for acute osteoporotic vertebral fracture among older women. Eur Spine J 2016;25:3424–31. https://doi.org/10.1007/s00586-015-3805-5
41. Roxburgh BH, Nolan PB, Weatherwax RM, et al. Is moderate intensity exercise training combined with high intensity interval training more effective at improving cardiorespiratory fitness than moderate intensity exercise training alone? J Sports Sci Med 2014;13:702.
42. Little JP, Jung ME, Wright AE, et al. Effects of high-intensity interval exercise versus continuous moderate-intensity exercise on postprandial glycemic control assessed by continuous glucose monitoring in obese adults. Appl Physiol Nutr Metabol 2014;39:835–41. https://doi.org/10.1139/apnm-2013-0512
43. Manders R, Van Dijk J, Van Loon L. Low-intensity exercise reduces the prevalence of hyperglycemia in type 2 diabetes. Med Sci Sports Exerc 2010;42:219–25. https://doi.org/10.1249/MSS.0b013e3181b3b16d