Association of Resistance Exercise, Independent of and Combined With Aerobic Exercise, With the Incidence of Metabolic Syndrome

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Abstract

Objective: To determine the association of resistance exercise, independent of and combined with aerobic exercise, with the risk of development of metabolic syndrome (MetS).

Patients and Methods: The study cohort included adults (mean ± SD age, 46±9.5 years) who received comprehensive medical examinations at the Cooper Clinic in Dallas, Texas, between January 1, 1987, and December, 31, 2006. Exercise was assessed by self-reported frequency and minutes per week of resistance and aerobic exercise and meeting the US Physical Activity Guidelines (resistance exercise $\geq$2 d/wk; aerobic exercise $\geq$500 metabolic equivalent min/wk) at baseline. The incidence of MetS was based on the National Cholesterol Education Program Adult Treatment Panel III criteria. We used Cox regression to generate hazard ratios (HRs) and 95% CIs.

Results: Among 7418 participants, 1147 (15%) had development of MetS during a median follow-up of 4 years (maximum, 19 years; minimum, 0.1 year). Meeting the resistance exercise guidelines was associated with a 17% lower risk of MetS (HR, 0.83; 95% CI, 0.73-0.96; *P*=.009) after adjusting for potential confounders and aerobic exercise. Further, less than 1 hour of weekly resistance exercise was associated with 29% lower risk of development of MetS (HR, 0.71; 95% CI, 0.56-0.89; *P*=.003) compared with no resistance exercise. However, larger amounts of resistance exercise did not provide further benefits. Individuals meeting both recommended resistance and aerobic exercise guidelines had a 25% lower risk of development of MetS (HR, 0.75; 95% CI, 0.63-0.89; *P*<.001) compared with meeting neither guideline.

Conclusion: Participating in resistance exercise, even less than 1 hour per week, was associated with a lower risk of development of MetS, independent of aerobic exercise. Health professionals should recommend that patients perform resistance exercise along with aerobic exercise to reduce MetS.

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One-third of US adults have metabolic syndrome (MetS).[1] Cardiometabolic disorders, such as glucose intolerance, insulin resistance, central obesity, dyslipidemia, and hypertension, are its key components.[2,3] Therefore, MetS is an important risk factor for type 2 diabetes mellitus[4,5] and cardiovascular diseases (CVDs).[6,7] Increasing physical activity (PA) is a cornerstone for preventing and treating MetS.[3,8] Several intervention studies have reported the benefits of aerobic exercise for improving metabolic risk factors.[9,10]

Previous studies, mostly cross-sectional, have identified negative associations of muscular strength[11-14] or resistance exercise[15-17] with the prevalence of MetS. Furthermore, recent cohort studies have indicated that higher levels of resistance exercise were associated with lower risks of type 2 diabetes mellitus in men and women,[18-20] which suggests that increasing resistance exercise might be a potential target for preventing MetS. However, there is very little evidence from large epidemiological studies regarding the effects of resistance exercise on the development of MetS. Therefore, the aim of this study was to examine the association of resistance exercise, independent of and combined with aerobic exercise, with the risk of development of MetS in relatively healthy

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middle-aged adults. We hypothesized that resistance exercise lowers the risk of development of MetS and that the combination of resistance and aerobic exercise might be more strongly associated with lower risk than either one independently.

PATIENTS AND METHODS

Study Population

The Aerobics Center Longitudinal Study is a cohort of men and women who received extensive preventive medical examinations at the Cooper Clinic in Dallas, Texas, between January 1, 1987, and December 31, 2006. Of the 10,243 participants, we excluded 836 individuals with a history of myocardial infarction, stroke, or cancer and 1989 individuals with MetS at baseline. Our final sample included 7418 individuals (1384 women [19%]). The participants were predominantly non-Hispanic whites, well educated, and employed in, or retired from, professional or executive positions.[21] The Cooper Institute institutional review board approved the study annually, and written informed consent was obtained from participants before data collection at baseline and during follow-up examinations.

Clinical Examination

All participants underwent comprehensive medical examinations at baseline, including body composition assessments, blood chemistry analyses, blood pressure measurements, electrocardiography, physical examination, and detailed medical history questionnaire. Body mass index (BMI) was calculated from measured weight and height squared (kg/m^2). Waist circumference was measured with anthropometric tape at the umbilicus level. Blood chemistry analyses, measuring triglyceride, high-density lipoprotein cholesterol (HDL-C), and fasting glucose levels, were obtained with automated bioassays after 12-hour fasting. Resting systolic and diastolic blood pressure were measured by standard auscultatory methods after 5 minutes of seated rest and calculated as the average of at least 2 readings separated by 2 minutes.

Age, sex, smoking status, alcohol consumption, personal history of physician-diagnosed CVD, cancer, and parental history of CVD, hypertension, and diabetes were assessed by a medical history questionnaire. Heavy alcohol drinking was defined as more than 14 alcoholic drinks per week for men and more than 7 for women.[22] The medical history questionnaire included a PA section on self-reported leisure time PA or recreational PA during the preceding 3 months. We classified aerobic exercise into 4 categories: inactive (0 metabolic equivalent [MET] min/wk), insufficient (1-499 MET min/wk), medium (500-999 MET min/wk), and high (≥1000 MET min/wk) based on the 2008 US Physical Activity Guidelines.[23]

Assessment of Resistance Exercise

Self-reported resistance exercise was assessed in the medical history questionnaire. Participants were asked about the weekly frequency and average exercise duration (minutes) for each session of muscle-strengthening PA using either free weights or weight training machines over the preceding 3 months. We used frequency (0, 1, 2, 3, 4, or ≥5 times/wk) and total amount (0, 1-59, 60-119, 120-179, and ≥180 min/wk) of resistance exercise as well as meeting the 2008 Physical Activity Guidelines for resistance exercise (≥2 times/wk[23]) as our main exposures. The total amount of resistance exercise was calculated by multiplying frequency of exercise with the average minutes per session.

Ascertainment of MetS

Participants were classified as having MetS using the criteria of the National Cholesterol Education Program Adult Treatment Panel III[3] at both baseline and follow-up. MetS was based on the presence of 3 or more of the following risk factors: (1) abdominal or central obesity (waist circumference >102 cm in men and >88 cm in women), (2) fasting hypertriglyceridemia (triglyceride level ≥150 mg/dL [to convert to mmol/L, multiply by 0.0113]), (3) low HDL-C level (<40 mg/dL in men and <50 mg/dL in women [to convert to mmol/L, multiply by 0.0259]), (4) high blood pressure (≥130/85 mm Hg or history of physician-diagnosed hypertension), and (5) high fasting glucose level (≥100 mg/dL [to convert to mmol/L, multiply by 0.0555] or history of physician-diagnosed diabetes). Follow-up time was calculated from the baseline examination to the first event of MetS or

TABLE 1. Baseline Characteristics of the 7418 Participants Stratified by Weekly Minutes of Resistance Exercise[a,b,c]

	Resistance exercise (min/wk)					
Characteristic	0 (n=4633)	1-59 (n=670)	60-119 (n=1061)	120-179 (n=502)	≥180 (n=552)	*P* value
Age (y)	46.7±9.7	45.9±8.3	46.2±9.0	45.1±9.5	43.7±10.1	<.001
Sex (male)	3795 (82)	568 (85)	856 (81)	369 (74)	446 (81)	<.001
BMI (kg/m^2)	25.3±3.2	24.9±2.9	24.9±3.0	24.8±3.2	24.8±3.1	<.001
Current smokers	522 (11)	56 (8)	93 (9)	57 (11)	60 (11)	.04
Heavy alcohol drinking	562 (12)	77 (11)	132 (12)	60 (12)	64 (12)	.98
Aerobic exercise (MET min/wk)						<.001
0	1125 (24)	40 (6)	45 (4)	32 (6)	42 (8)	
1-499	708 (15)	89 (13)	117 (11)	65 (13)	73 (13)	
500-999	899 (19)	135 (20)	246 (23)	115 (23)	95 (17)	
≥1000	1901 (41)	406 (61)	653 (62)	290 (58)	342 (62)	
Abnormal ECG	387 (8)	53 (8)	69 (7)	29 (6)	34 (6)	.05
Parental history of cardiovascular disease	1177 (25)	162 (24)	255 (24)	130 (26)	132 (24)	.79
Parental history of hypertension	1602 (35)	251 (37)	379 (36)	191 (38)	184 (33)	.28
Parental history of diabetes	632 (14)	91 (14)	134 (13)	61 (12)	67 (12)	.71
Metabolic syndrome						
Waist circumference (cm)	88.5±11.0	86.8±10.3	86.0±10.7	84.5±11.1	84.9±10.3	<.001
Triglycerides (mg/dL)	103.4±59.6	92.9±44.3	97.0±52.4	96.0±53.1	94.4±59.6	<.001
HDL-C (mg/dL)	53.0±14.5	55.0±14.6	55.1±14.4	56.6±14.7	54.9±14.3	<.001
Systolic blood pressure (mm Hg)	119±13	119±13	119±13	119±13	120±13	.67
Diastolic blood pressure (mm Hg)	79±9	80±9	79±9	79±10	80±9	.62
Fasting glucose (mg/dL)	96.2±10.1	96.5±13.0	96.2±11.9	95.6±11.4	96.2±13.3	.77

[a] BMI = body mass index; ECG = electrocardiographic findings; HDL-C = high-density lipoprotein cholesterol; MET = metabolic equivalent.

[b] Data are presented as mean ± SD or No. (percentage) of participants.

[c] SI conversion factors: To convert triglycerides to mmol/L, multiply by 0.0113; to convert HDL-C to mmol/L, multiply by 0.0259; to convert glucose to mmol/L, multiply by 0.0555.

the last follow-up examination through 2006 for individuals who did not have development of MetS.

Statistical Analyses

Baseline characteristics were summarized as mean and SD for continuous variables and as number and percentage for categorical variables. Baseline differences for participants with different amounts of resistance exercise were examined using analysis of variance for continuous variables and χ^2 tests for categorical variables.

Cox proportional hazards regression was used to compute hazard ratios (HRs) and their 95% CIs for MetS across different amounts and frequencies of resistance exercise. Participants who reported no resistance exercise were used as the reference category. The regression models were adjusted for age, sex, examination year, BMI, current smoking, heavy alcohol drinking, abnormal electrocardiographic findings, parental history of CVD, hypertension, and diabetes, and aerobic exercise (inactive, insufficient, medium, and high). In addition, we examined the independent and combined effects of meeting aerobic (≥500 MET min/wk[23]) and/or resistance exercise guidelines on the risk of development of MetS in the combined analyses.

To examine potential effect modification by sex in the association between resistance exercise and incident MetS, we tested interaction terms of sex and resistance exercise using Cox regression. In addition, we compared risk estimates in sex-stratified analyses. We did not find any significant interaction (P=.56), and trends of development of MetS in men and women were similar. Therefore, we presented the results of pooled analyses. All statistical tests were 2-sided, and significance was set at P<.05. All analyses were conducted using SAS statistical software, version 9.4 (SAS Institute).

TABLE 2. Hazard Ratios for Metabolic Syndrome in 7418 Study Participants Stratified by Weekly Frequency and Minutes of Resistance Exercise[a]

Variable	No. (%) of participants	No. of MetS cases	Adjusted hazard ratio (95% CI)		
			Model 1[b]	Model 2[c]	Model 3[d]
Weekly minutes of resistance exercise					
0	4633 (62)	816	1.00 [Reference]	1.00 [Reference]	1.00 [Reference]
1-59	670 (9)	80	0.62 (0.49-0.78)	0.69 (0.55-0.86)	0.71 (0.56-0.89)
60-119	1061 (14)	141	0.83 (0.69-0.99)	0.93 (0.77-1.11)	0.96 (0.80-1.16)
120-179	502 (7)	51	0.66 (0.50-0.88)	0.78 (0.59-1.04)	0.81 (0.61-1.07)
≥180	552 (7)	59	0.65 (0.50-0.85)	0.76 (0.58-0.99)	0.78 (0.60-1.02)
P for trend			<.001	.006	.03
Any resistance exercise					
No (0 min/wk)	4633 (62)	816	1.00 [Reference]	1.00 [Reference]	1.00 [Reference]
Yes (≥1 min/wk)	2785 (38)	331	0.71 (0.62-0.80)	0.80 (0.71-0.91)	0.83 (0.72-0.95)
Weekly frequency of resistance exercise					
0	4633 (62)	816	1.00 [Reference]	1.00 [Reference]	1.00 [Reference]
1	206 (3)	22	0.80 (0.53-1.23)	0.81 (0.53-1.24)	0.83 (0.54-1.27)
2	766 (10)	83	0.72 (0.58-0.91)	0.81 (0.65-1.02)	0.84 (0.67-1.06)
3	1221 (16)	163	0.77 (0.65-0.91)	0.86 (0.72-1.01)	0.88 (0.74-1.05)
4	339 (5)	32	0.48 (0.34-0.68)	0.60 (0.42-0.86)	0.62 (0.44-0.89)
≥5	253 (3)	31	0.66 (0.46-0.95)	0.79 (0.55-1.13)	0.81 (0.56-1.16)
P for trend			<.001	.001	.005
Recommended resistance exercise					
No (<2 d/wk)	4839 (65)	838	1.00 [Reference]	1.00 [Reference]	1.00 [Reference]
Yes (≥2 d/wk)	2579 (35)	309	0.71 (0.62-0.80)	0.81 (0.71-0.92)	0.83 (0.73-0.96)

[a] MetS = metabolic syndrome.

[b] Adjusted for age, sex, and examination year.

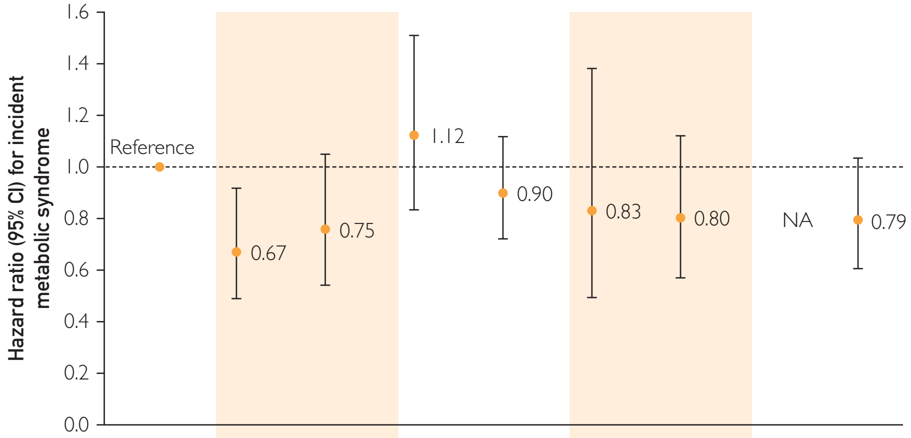
[c] Adjusted for model 1 plus body mass index, current smoking, heavy alcohol drinking, abnormal electrocardiographic findings, and parental history of cardiovascular disease, hypertension, and diabetes.

[d] Adjusted for model 2 plus aerobic exercise (inactive, insufficient, medium, and high).

RESULTS

Among 7418 participants, 1147 (15%) had development of MetS during a median follow-up of 4 years (maximum, 19 years; minimum, 0.1 year) (Table 1). Among individuals who participated in resistance exercise (2785 [38%]), resistance exercise was most frequently performed for 60 to 119 min/wk (1061 [38%]). Compared with individuals not performing resistance exercise, individuals with higher levels of resistance exercise were more likely to be younger, leaner (lower BMI and waist circumference), and aerobically active. However, the proportion of men decreased with higher levels of resistance exercise. Individuals who participated in resistance exercise were also less likely to smoke and had more favorable lipid profiles (lower triglycerides and higher HDL-C levels; all *P*<.05).

Performing any resistance exercise was associated with a 17% lower risk of development of MetS (HR, 0.83; 95% CI, 0.72-0.95; *P*=.006) after adjusting for potential confounders, including aerobic exercise levels in the fully adjusted model 3 (Table 2). Meeting the resistance exercise guidelines had a similar 17% lower risk of MetS (HR, 0.83; 95% CI, 0.73-0.96; *P*=.009) in the full model (model 3). Furthermore, we found that resistance exercise at 1 to 59, 60 to 119, 120 to 179, and 180 or more minutes per week were all associated with lower HRs for MetS (all *P*<.05) compared with no resistance exercise after adjusting for age, sex, and examination year (model 1). However, after further adjustment for other potential confounders and aerobic exercise levels (model 3), only 1 to 59 minutes per week of resistance exercise was associated with a 29% reduced risk of MetS (HR, 0.71; 95% CI, 0.56-0.89; *P*=.003). We also found that 4 days per week of resistance exercise was associated with a 38% lower risk of development of MetS (HR, 0.62; 95% CI, 0.44-0.89; *P*=.009) compared with no



Frequency	0	1-2	≥3	1-2	≥3	1-2	≥3	1-2	≥3
Min/wk	0	1-59		60-119		120-179		≥180	
No. of cases	816	42	38	48	93	15	36	0	59
No. of participants (%)	4633 (62%)	407 (6%)	263 (4%)	386 (5%)	675 (9%)	164 (2%)	338 (5%)	15 (<1%)	537 (7%)

FIGURE 1. Hazard ratios for metabolic syndrome by the combination of weekly frequency (1-2 vs ≥3 times/wk) and minutes of resistance exercise (0, 1-59, 60-119, 120-179 and ≥180 min/wk). The dots indicate hazard ratios and the lines present 95% CIs. The model was adjusted for age (years), sex, examination year, body mass index (kg/m^2), current smoking (yes/no), heavy alcohol drinking (yes/no), abnormal electrocardiographic findings (yes/no), parental history of cardiovascular disease, hypertension, and diabetes (yes/no for each), and aerobic exercise (inactive, insufficient, medium, and high). Analysis in the category of 180 minutes or more in 1 to 2 sessions of resistance exercise per week was not applicable (NA).

resistance exercise in the fully adjusted model (model 3). In additional analyses after further adjustment for the number of MetS risk factors (0, 1, or 2) at baseline, the results were virtually the same in that the risk of development of MetS was 14% lower in individuals performing any resistance exercise (HR, 0.86; 95% CI, 0.75-0.98; *P*=.02), 14% lower in individuals meeting the recommended guidelines (HR, 0.86; 95% CI, 0.75-0.99; *P*=.03), 26% lower in individuals performing resistance exercise less than 1 hour per week (HR, 0.74; 95% CI, 0.58-0.93; *P*=.01), and 33% lower in individuals performing resistance exercise 4 times per week (HR, 0.67; 95% CI, 0.47-0.95; *P*=.03).

In addition, we examined the risk of MetS among individuals with the same total amount of weekly resistance exercise (minutes per week) but at different frequencies (1-2 vs ≥3 times/wk). For example, some people may perform 2 hours of weekly resistance exercise in 1 or 2 sessions, especially during weekends (so-called weekend warriors), whereas others may perform the same 2 hours of weekly resistance exercise in more than 2 sessions.

The joint analysis of frequency and total amount of resistance exercise (Figure 1) did not reveal any significant differences in the risk of development of MetS between less frequent (1-2 times/wk) and more frequent (≥3 times/wk) exercisers among individuals with the same total amount of weekly resistance exercise (all *P*>.05). However, we observed a 33% lower risk of development of MetS (HR, 0.67; 95% CI, 0.49-0.91; *P*=.01) in individuals who performed resistance exercise 1 to 2 times per week with a total exercise amount of 1 to 59 minutes per week. Further, we found no difference in incident MetS in individuals performing 1 to 59 minutes per week of resistance exercise for less than 1 year and more than 1 year (*P*>.05).

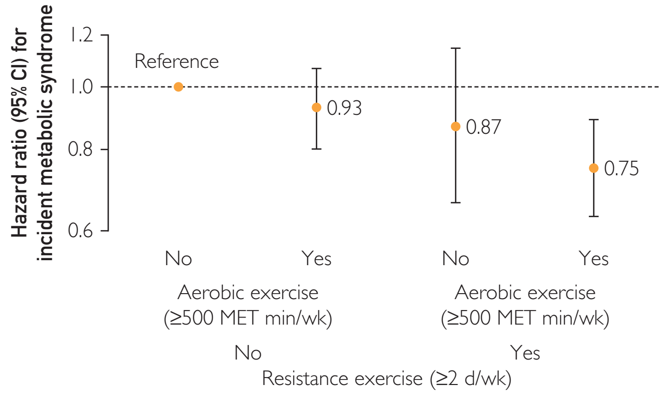


FIGURE 2. Hazard ratios for metabolic syndrome by meeting the 2008 US Physical Activity Guidelines for resistance (≥2 d/wk) and aerobic (≥500 metabolic equivalent [MET] min/wk) activities at baseline. The dots present hazard ratios and the lines the 95% CIs. The model was adjusted for age (years), sex, examination year, body mass index (kg/m^2), current smoking (yes/no), heavy alcohol drinking (yes/no), abnormal electrocardiographic findings (yes/no), and parental history of cardiovascular disease, hypertension, and diabetes (yes/no for each).

Figure 2 illustrates the independent and combined associations of meeting the resistance and/or aerobic exercise guidelines with incident MetS. We found that individuals meeting both recommended resistance and aerobic exercise guidelines had a 25% lower risk of development of MetS (HR, 0.75; 95% CI, 0.63-0. 89; $P<.001$) compared with individuals meeting neither guideline.

DISCUSSION

This large cohort study yielded 3 major study findings. First, we documented that participating in resistance exercise, independent of aerobic exercise, significantly decreases the risk of development of MetS compared with no resistance exercise in a middle-aged relatively healthy population ($P=.006$). Specifically, less than 1 hour per week of resistance exercise resulted in significantly lower risk of MetS compared with no resistance exercise ($P=.003$). However, higher volumes of resistance exercise did not provide further benefits (Table 2), suggesting against the "more is better" philosophy. Second, the combined analysis of weekly frequency and total amount of resistance exercise (Figure 1) showed no effect of exercise frequency in incident MetS at a given total volume of resistance exercise. Therefore, resistance exercise for less than 1 hour per week, regardless of training frequency, may be important in preventing MetS. Third, meeting both resistance and aerobic exercise guidelines was associated with 25% lower risk of development of MetS compared with meeting neither of these guidelines (Figure 2). This finding suggests additional benefits of doing both resistance and aerobic exercise for the prevention of MetS.

Previous studies have indicated a negative association of muscular strength and MetS, which was still present after adjusting for aerobic fitness.[12] However, the protective effect of muscular strength against MetS might be explained by regular participation in resistance exercise because resistance exercise is a major determinant of muscular strength.[24,25] Cross-sectional studies of muscle-strengthening PA have also reported a negative association with the prevalence of MetS,[15-17] which is in line with our findings. Nevertheless, those prior studies only investigated the effect of participating in resistance exercise (yes/no) or meeting the resistance exercise guidelines (yes/no). Conversely, our study further examined the dose-response relationship between resistance exercise and incident MetS across different weekly frequencies and total amounts of resistance exercise. In addition, we also examined the independent and combined effects of resistance and aerobic exercise on the development of MetS.

Several studies have investigated the associations between resistance exercise and type 2 diabetes mellitus, another common metabolic disease. Grøntved et al[19,20] found a reduced risk of type 2 diabetes mellitus with performance of less than 1 hour of resistance exercise per week in 32,000 men and 99,000 women. In addition, they found that a combination of aerobic and resistance exercise was superior in preventing type 2 diabetes mellitus. We obtained similar results for the prevention of MetS. Further, they found a linear dose-response relationship between the amount of resistance exercise and the risk of incident type 2 diabetes mellitus. In contrast, however, we did not observe a linear dose-response relationship between resistance exercise and the risk of development of MetS, suggesting against the "more is better" hypothesis regarding resistance exercise and development of MetS. However, this finding might be at least partially due to the smaller sample size and number of cases in our study. It is also possible that resistance exercise dose-response curves may be different between MetS and type 2 diabetes mellitus. These contradictory findings suggest that further investigations on dose-response relationships between resistance exercise and different health outcomes are clearly warranted. We also investigated the dose-response relationship between the frequency of resistance exercise and risk of MetS, documenting significant benefits of performing resistance exercise 4 times per week (P=.03). However, this result is somewhat complicated because the frequency does not necessarily fully represent the total amount of resistance exercise. Therefore, the prescription of frequency in the current resistance exercise guidelines may lack sufficient detail, whereas a prescription of total minutes per week might be more appropriate.

The current study found no significant difference in the risk of MetS between 1 to 59 and 180 or more minutes per week of resistance exercise (P>.05), which suggests no additional benefits of higher levels of resistance exercise on the development of MetS. In addition, the dose-response relationship between resistance exercise and MetS may not be linear but reverse J-shaped, which has been found in studies regarding aerobic exercise and cardiovascular health.[26-28] Although it is not clear why there are no further benefits on incident MetS by increasing the amount of resistance exercise, it may be related to no significant differences in systolic or diastolic blood pressure and fasting glucose levels across different amounts of resistance exercise (P=.67, P=.62, and P=.77, respectively), as shown in Table 1. However, more favorable lipid profiles (triglyceride and HDL-C levels) with increasing resistance exercise (Table 1) may partially explain the benefits of resistance exercise on the development of MetS because blood lipids are the components of MetS. Furthermore, additional analyses revealed no significant differences in risk of MetS in individuals performing 1 to 59 minutes of resistance exercise weekly for less than 1 year and more than 1 year (P>.05). A possible explanation could be the absence of training progression (no gradual increase in amount and/or intensity of resistance exercise) after a certain period, which results in a stabilization of the muscle mass and strength and therefore no further health benefits. Future studies of long-term resistance exercise training with different doses and intensities are therefore needed to determine the protection against MetS as well as CVD.

In 2004, Lee et al[29] introduced the concept of "weekend warriors," individuals who meet the aerobic exercise guidelines but perform their PA in 1 to 2 days per week, possibly during weekends. They found that weekend warriors still had mortality benefits compared with sedentary individuals, but their benefits were less compared with individuals who were regularly physically active, especially in individuals with major CVD risk factors such as smoking, overweight, and hypertension. In our study, there was no effect of increased frequency with the same amount of resistance exercise (all P>.05). Nevertheless, only individuals performing 1 to 59 minutes of resistance exercise in 1 to 2 sessions per week had significantly lower risk of MetS compared with no resistance exercise (P=.01). This finding suggests that even a relatively small amount of resistance exercise once or twice per week may be enough to maximally reduce the risk of MetS, at least from the resistance exercise perspective. However, it should be mentioned that the sample sizes and number of cases were smaller in categories with higher levels of resistance exercise, which reduced the statistical power in these groups.

MetS is more prevalent in older and overweight individuals.[1] However, subgroup analyses in our study appear to confirm similar negative trends, P>.05 for resistance exercise and MetS in different BMI (<25 vs ≥25 kg/m^2) and age (<50 vs ≥50 years) groups (data not shown). The lack of statistical significance was probably due to the small number of participants and MetS cases across these strata. Nevertheless, the reduced risk of MetS by resistance exercise remained significant after adjusting for BMI and age and documents consistency in our findings.

The strengths of this study include a large cohort with a relatively long follow-up. Furthermore, we believe that this is the first prospective study that investigated the association between resistance exercise and incident MetS. However, limitations of our study include self-reported data on PA, which may cause measurement errors due to overreporting of leisure time PA.[30] Nevertheless, overreporting generally causes an underestimation of the true effect of exercise on health outcomes.[31] Only baseline levels of PA were used for the analyses, and therefore changes in PA patterns were not included in the study. Our study includes primarily well-educated non-Hispanic whites from middle to upper socioeconomic strata, which may limit the generalizability of the results; thus, the findings may be different in other populations. Conversely, homogeneity in ethnicity and socioeconomic status reduces potential confounding by race/ethnicity, education, and income. Physiologic characteristics of this cohort are also similar to those of other representative population samples.[21] Another limitation is that we had no information about medications to include in the analyses. Although we adjusted for potential confounders such as medical conditions (eg, hypertension, diabetes, and abnormal electrocardiographic findings) and lifestyle factors (eg, smoking, alcohol intake, and BMI), randomized controlled trials of resistance exercise are warranted to remove those confounding biases in the future.

CONCLUSION

Meeting the resistance exercise guidelines, independent of aerobic exercise, decreases the risk of development of MetS in a middle-aged adult population. In particular, relatively smaller amounts of resistance exercise, less than 1 hour in 1 to 2 sessions per week as could be seen in the weekend warrior profile, resulted in the highest reduction in the risk of development of MetS compared with no resistance exercise. Also, meeting both resistance and aerobic exercise guidelines is superior in preventing MetS. Therefore, resistance exercise, independent of and combined with aerobic exercise, should be included in PA routines for the prevention of MetS. Clinicians should routinely recommend resistance exercise training, in addition to aerobic training, for the prevention of MetS and future CVD risk. In addition, individuals with CVD risk factors should consider a more individualized, safe, and effective exercise program under the direction of a qualified exercise professional.

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Abbreviations and Acronyms: **BMI** = body mass index; **CVD** = cardiovascular disease; **HDL-C** = high-density lipoprotein cholesterol; **HR** = hazard ratio; **MET** = metabolic equivalent; **MetS** = metabolic syndrome; **PA** = physical activity

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