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Effects of physical fitness training on metabolic syndrome among military personnel in Taiwan

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► Additional material is published online only. To view, please visit the journal online (<http://dx.doi.org/10.1136/bmjilitary-2020-001761>).

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Received 27 December 2020

Revised 20 January 2021

Accepted 21 January 2021

Published Online First

4 February 2021

ABSTRACT

Introduction Metabolic syndrome (MS) is strongly associated with cardiovascular diseases and diabetes but can be prevented with regular physical activity. This study aimed to assess the impact of a physical fitness training programme on MS among military personnel.

Methods This retrospective observational study included volunteer army soldiers who underwent annual health examinations between 2011 and 2014. In 2011, the reformed physical fitness training programme and physical fitness test were introduced to the participants. MS evaluation and physical fitness performances were evaluated before and after implementing the training programme using a mixed-effects model and generalised estimating equation, adjusted for sex, age and smoking.

Results From 2011 to 2014, 1720 soldiers underwent the annual health examination. In 2011, before the fitness programme, 246 soldiers (14.3%) had MS. After implementation, decreases in blood pressure and fasting glucose levels were observed and maintained for 3 years. Running performance was negatively correlated to triglycerides ($\beta=-11.37$; $p<0.001$) and waist circumference ($\beta=-0.42$; $p<0.001$) and positively correlated to high-density lipoprotein cholesterol levels ($\beta=2.14$; $p<0.001$). The severity of MS was reduced following introduction of the physical fitness programme.

Conclusions MS and its components improved after introducing the reformed fitness programme, with running performance proving to be most relevant to MS. Clinicians should encourage increased physical activity to prevent MS among military personnel.

INTRODUCTION

Metabolic syndrome (MS) was first understood and reported to be related to insulin resistance in 1988.¹ In 1990, the WHO defined the syndrome and the metabolic abnormalities involved, including insulin resistance, central obesity, hyperlipidaemia, hypertension and other cardiovascular disease risk factors.^{2 3} Subsequently, the US National Heart, Lung, and Blood Institute proposed the National Cholesterol Education Program's Adult Treatment Panel III in accordance with a clinical study, examining the risk factors and blood lipid concentration standards, to further reinforce the involvement of multiple risk factors and the importance of primary and secondary prevention (Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults 2001).⁴ Moderate to vigorous physical activity has been shown to reduce risk factors for MS, whereas a sedentary lifestyle is associated with a higher incidence of MS.^{5 6} Despite the general belief that military service jobs

Key messages

- ⇒ This retrospective cohort study determined whether the physical fitness programme improved the health status of military personnel.
- ⇒ This study makes a significant contribution to the literature because we used a physical fitness test to quantify the effects of cardiorespiratory fitness training.
- ⇒ Results showed that running performance had a significantly negative association with waist circumference, triglyceride levels, fasting glucose and a positive association with high-density lipoprotein cholesterol.
- ⇒ Clinicians should encourage increased physical activity to prevent metabolic syndrome among military personnel.

are physically demanding, the estimated prevalence of MS in the military is 21% globally, and surprisingly, some cardiometabolic risk factors are higher in this population than in the general population.⁷ The impact of physical training on the occurrence of MS in military populations has not been well investigated.

It is generally recognised and accepted that military duties require high levels of physical fitness and performance.⁸ In Taiwan, all military personnel on active duty are required to undergo basic physical training to ensure soldiers' physical fitness. Performance in the annual physical fitness test (PFT) is considered in evaluating military personnel for promotion. In the past, basic physical fitness training involved autonomous training, and there were no definitive guidelines. In 2012, a reform of the basic physical training programme was introduced, including more rigorous daily, weekly and monthly training and evaluation, using standardised guidelines and goals. Additionally, the modified PFT was implemented in 2012. It is unknown whether basic physical training programmes with clearer guidelines and goals affect the risk of MS and which components of MS are affected in military services. This study aimed to conduct a longitudinal follow-up study to determine whether the reform of the basic physical training programme affected MS and its contributory factors.

METHODS

This retrospective study was approved by the Institutional Review Board (TSGHIRB No. 1-105-05-104). All authors have completed the disclosure



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To cite: Chang C-F, Wu Y-C, Lai C-H, et al. *BMJ Mil Health* 2023;**169**:e15–e19.

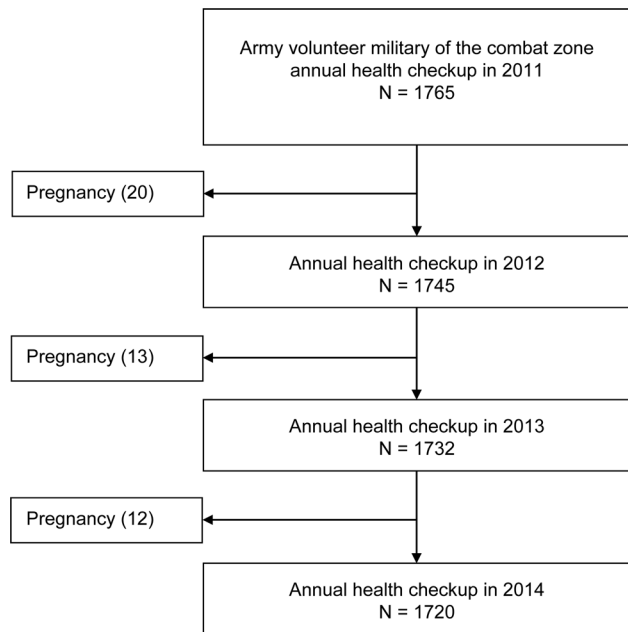


Figure 1 Study design. Volunteer soldiers completed the annual health check-up and the physical fitness tests in 2011, participated in the modified physical fitness programme, received annual health check-up results and were tested using the modified test standards from 2012 to 2014

form and declare that no support, financial or otherwise, has been received from any organisation that may have an interest in the submitted work, and there are no other relationships or activities that could appear to have influenced the submitted work.

Participants

Figure 1 shows the participant recruitment scheme. Electronic record data excluding personal identifying information were obtained from the military health examination databank. The volunteer soldiers who completed the annual physical examination from 2011 to 2014 and those who adopted the training and fitness testing under the 2012 reformed physical fitness programme were included. Candidates who became pregnant during the study or within 4 years of follow-up were excluded.

Outcome measurements and health indices

From 2011 to 2014, annual health examinations were performed on volunteer soldiers before the PFT. All clinical measurements were conducted in the morning after at least 8 hours of fasting. Waist circumference (WC) was measured at the umbilicus level using a plastic anthropometric tape, and blood pressure (BP) was measured using an automated sphygmomanometer. Blood samples were taken from all study participants between 08:00 and 10:00 hours after at least 8 hours of overnight fasting. Fasting blood samples were obtained by venepuncture, and the levels of serum triglycerides (TG), high-density lipoprotein cholesterol (HDL-C) and plasma glucose were assayed at a certified laboratory using automated techniques.

The study participants were diagnosed as having MS if they had three or more of the following five risk factors, based on the International Diabetes Federation guidelines.⁹

1. WC (South Asians): ≥ 90 cm (men) and ≥ 80 cm (women).
2. TG: ≥ 150 mg/dL.
3. HDL-C: < 40 mg/dL (men) and < 50 mg/dL (women)

4. BP: systolic BP (SBP) ≥ 130 mm Hg or diastolic BP ≥ 85 mm Hg or treatment of previously diagnosed hypertension.
5. Fasting plasma glucose ≥ 100 mg/dL or previous diagnosis of type 2 diabetes mellitus.

Intervention

Before 2012, the basic physical fitness involved autonomous training with no definite guidelines, and the annual PFT included 3 km of running, 1 min of push-ups and 1 min of sit-ups. Mandatory training involved an estimated 18 MET-hours/week. After 2012, the reformed basic physical fitness training programme involved two times a day performance (morning and evening 06:00 to 07:00 hours and 16:30 to 18:30 hours, respectively), at least 3–5 times weekly as a group. Every training session reached an exercise intensity of ≥ 8 MET-hours/day. Sessions in the training programme included cardiorespiratory fitness (4–4.5 km runs and four short distance (100 m) sprints), strength training (including 40 sit-ups and 40 push-ups) in uniform, lasting 60 min for every training session. The 2012 modified PFT included 3 km of running, 2 min of push-ups and 2 min of sit-ups. The 3 km run was performed outdoors under consistent weather conditions on a level, paved surface. Sit-ups were used as a measure of muscular endurance of the trunk and hip flexors. The participants started the sit-ups in a supine position with the knees at a 90° angle while being held by a partner. The upper body was raised in a manner in which the elbow touched the opposite knee. Push-ups were used as a measure of muscular endurance of the arm, shoulder and chest. The participants began the push-ups with a straight body with the chest and cheek touching the floor. The upper body was then raised until the arms were straight. The maximum numbers of repetitions for sit-ups and push-ups in 2 min were measured. Monthly tests were performed in each unit and annually at a national testing centre. The physical test results at the national centre were recorded in the personal files of the military personnel. The passing criteria for the test were also restandardised; for example, a 23-year-old male officer was required to complete the 3 km run in 14 min and 25 s (compared with 15 min and 20 s before 2012), to perform 50 push-ups in 2 min (32 push-ups in 1 min before 2012) and 42 sit-ups in 2 min (29 sit-ups in 1 min before 2012).¹⁰

Statistical analysis

MS and its components were compared before (2011) and after (2012–2014) the introduction of the 2012 physical fitness programme. The effects of the physical fitness programme on various risk factors of MS were assessed by employing a mixed-effects model and a multivariate generalised estimating equation (GEE) using performances in the PFT (as continuous variables) as independent variables. The MS components were explored using a mixed-effects model. ORs and 95% CIs were estimated using the GEE to determine the association of PFT with the prevalence of MS and its components. Two-sided $p < 0.05$ were considered significant. All of the covariates in the model were adjusted in the GEE and mixed-effects models. Covariates including age, sex, body mass index (BMI), alcohol intake and smoking were included in the analysis, considering their potential effects on MS as previously reported.¹¹ Crude ORs were obtained, as well as adjusted ORs, in which covariates with a significant p value (< 0.05) were included in the final model. Analyses were conducted using SAS V.9.4 and SPSS V.23.0.

Table 1 Generalised equation showing AORs and 95% CIs for metabolic syndrome*

Parameter	AOR	95% CI	P value
Gender (men vs women)	1.08	0.71 to 1.65	0.725
Age	1.09	1.06 to 1.11	<0.001
BMI	1.55	1.48 to 1.61	<0.001
1 year after the programme	0.74	0.62 to 0.89	0.002
2 years after the programme	0.62	0.52 to 0.75	<0.001
3 years after the programme	0.63	0.52 to 0.77	<0.001
Physical fitness test performance			
Sit-ups (repetitions)	0.99	0.96 to 1.02	0.651
Push-ups (repetitions)	0.99	0.97 to 1.02	0.670
Running (km/hour)	0.64	0.49 to 0.84	<0.001

Values were adjusted for smoking and alcohol drinking and mutually adjusted.
*AORs and 95% CIs are shown for metabolic syndrome after the physical fitness programme, comparing between the 2011 baseline results and the physical fitness test performance.
AOR, adjusted OR; ; BMI, body mass index.

RESULTS

Of the 1765 participants who underwent health examinations at an Armed Forces General Hospital, 45 women were excluded due to pregnancy during 2011–2014. The remaining 1720 participants were included in the final analyses (1462 men and 258 women). Online supplemental table 1 summarises the demographics of the participants selected in 2011. MS was diagnosed in 246 of the 1720 participants. The distribution of covariates into men/women for smoking, alcohol consumption, and the number of MS risk factors is shown in Table 1. In 2011, 32.6%, 33.6%, 18.5% and 15.3% had 0, 1, 2 or ≥ 3 factors, respectively. For women: 54.7%, 27.1%, 9.69% and 8.52% had 0, 1, 2 or ≥ 3 factors, respectively. Generally, a higher prevalence of elevated TG, high BP and high fasting plasma glucose was observed in male participants than in female participants. Male and female participants had a similar prevalence of larger WC (25.7% in men and 26.4% in women). The initial prevalence of MS was 14.3% in 2011 (Figure 2). The prevalence among men in the armed forces increased from 14.5% in the 30–39-year-old group to 19.1% in the 40–49-year-old group. Among women, it increased from 7.1% in the 30–39-year-old group to 25.0% in the 40–49-year-old group (Figure 3). Following the introduction

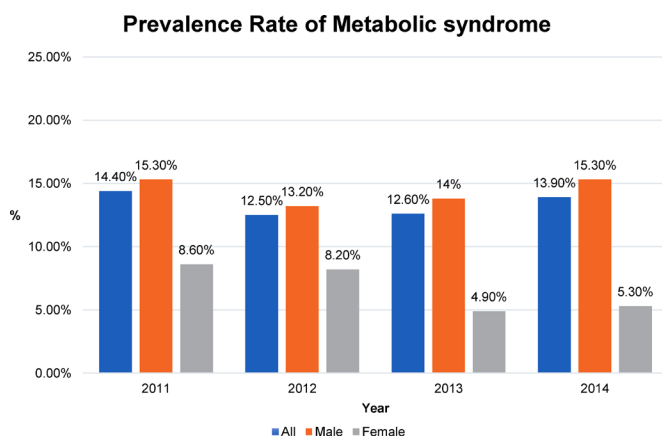
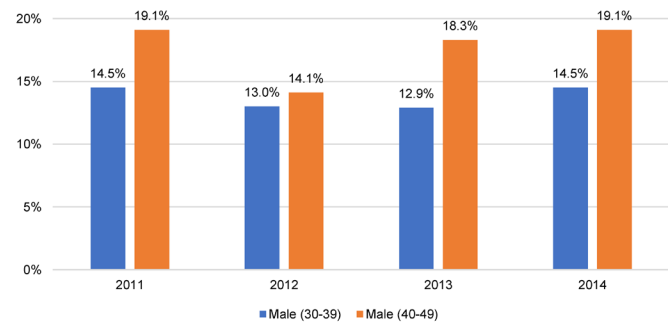


Figure 2 Prevalence of MS. The prevalence rate of MS was reduced in 2012 compared with that in 2011. Later on, such prevalence increased with age but generally remained lower than that in 2011. MS, metabolic syndrome.

A

Prevalence Rate of Metabolic Syndrome



B

Prevalence Rate of Metabolic Syndrome

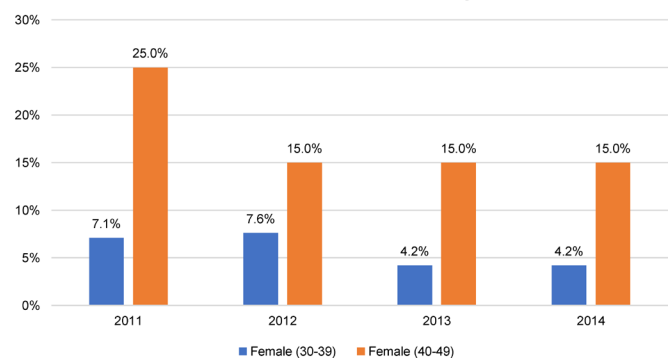


Figure 3 Age-specific prevalence of metabolic syndrome in (A) men and (B) women.

of the reformed PFT, the prevalence of MS decreased to 12.5%. Subsequently, the prevalence of MS increased with age over time but generally remained lower than that in 2011. Considering the number of participants, the power of detecting two-tailed statistics with an alpha level of 0.05, the statistical powers were estimated using McNemar's method for BP abnormality from 44.12% to 44.13%, WC abnormality from 25.87% to 31.45%, elevated fasting plasma glucose from 10.47% to 15.69%, elevated TG from 20.93% to 24.59% and low HDL-C from 14.6% to 23.77% to be 0.8, 0.99, 0.99, 0.96 and 0.99, respectively.

After the introduction of the reformed physical training programme in 2012, the ORs for MS were 0.743 (95% CI, 0.617 to 0.894; $p=0.002$), 0.626 (95% CI, 0.523 to 0.75; $p<0.001$) and 0.633 (95% CI, 0.522 to 0.767; $p<0.001$) in 2012, 2013 and 2014, respectively (Table 1). In addition, running performance was negatively associated with the risk of MS (Table 2).

Table 2 shows the relationship between performance of PFT and individual components of MS, adjusting for age, sex and BMI. The running speed was negatively correlated to WC ($\beta=-0.42$, $p<0.001$), TG ($\beta=-11.37$, $p<0.001$) and fasting glucose ($\beta=-0.54$, $p=0.054$) and positively correlated with HDL-C ($\beta=2.14$, $p<0.001$). The number of sit-ups in 2 min was negatively correlated with SBP ($\beta=-0.11$, $p=0.003$), TG ($\beta=-0.41$, $p=0.048$) and fasting glucose ($\beta=-0.07$, $p=0.003$) and positively correlated with HDL ($\beta=0.16$, $p<0.001$). The number of push-ups was negatively correlated to WC ($\beta=-0.05$, $p<0.001$).

DISCUSSION

This is the first study investigating the impact of introducing a physical training programme on the reduction of MS in military service. Additionally, performance in the annual tests was related

Table 2 Effects of physical fitness performance on the components of metabolic syndrome with the use of the mixed-effects model

Variable	Systolic blood pressure		Diastolic blood pressure		Waist circumference		Triglycerides		Fasting glucose		HDL cholesterol	
	β^*	<i>P</i> value	β^*	<i>P</i> value	β^*	<i>P</i> value	β^*	<i>P</i> value	β^*	<i>P</i> value	β^*	<i>P</i> value
# of sit-ups in 2 min	-0.11	0.003	-0.06	0.309	-0.02	0.231	-0.41	0.048	-0.07	0.003	0.16	<0.001
# of push-ups in 2 min	0.04	0.353	0.01	0.240	-0.05	<0.001	-0.12	0.626	-0.01	0.781	0.07	0.110
Running speed (km/hour)	-0.22	0.543	-0.12	0.239	-0.42	<0.001	-11.37	<0.001	-0.51	0.054	2.14	<0.001

*Adjusted for age, sex, smoking, alcohol drinking and body mass index (in 2011). HDL, high-density lipoprotein.

to factors affecting MS, including SBP, WC, serum TG, fasting glucose and HDL.

Physical activity plays an important role in the aetiology and management of MS.¹² While physical activity has long been regarded as an important component of a healthy lifestyle, poor cardiorespiratory fitness has been consistently associated with an increased risk of chronic diseases, including type 2 diabetes mellitus and cardiovascular disease.^{13–14} Negative associations between cardiorespiratory fitness and MS prevalence have been reported.^{15–17} A study showed a 31% reduction in MS prevalence among 105 adults after 20 weeks of aerobic physical training.¹⁸ Some studies using fitness exposure have demonstrated an inverse association with MS incidence, but the results of others using self-reported questionnaires have been ambiguous.¹⁹ In the 2012 physical fitness programme, every training activity achieved an exercise intensity of 8 MET-hours/day or greater and involved at least three training sessions per week. The total physical activity level was at least 24 MET-hours/week. To evaluate the effect of the reformed physical fitness programme, we used a retrospective cohort approach, instead of a cross-sectional method, to demonstrate the associations between physical fitness and MS. According to our analysis, compared with the baseline data, the risk of developing MS was reduced after introducing the physical fitness programme. The protective effect of the training was adjusted for possible confounders. Our findings indicate that the physical fitness programme substantially protected against MS and associated chronic conditions among military personnel.

Physical activity reduces cardiovascular disease risk, possibly because it improves the lipoprotein profile.²⁰ Based on the American College of Sports Medicine recommendation, physical activities with higher intensity are associated with higher HDL-C levels and lower levels of total cholesterol and TG.²¹ Studies have reported an inverse association between cardiorespiratory fitness and MS incidence.²² In our study, after adjustment for covariates, BP declined after the introduction of the modified PFT, and the effect was maintained in the second and third years. Furthermore, HDL-C levels significantly increased after introducing the modified PFT, and the effect was sustained. Fasting glucose levels decreased in the second and third years after the introduction.

Physical activities, such as running, correlate more strongly with the prevalence of diabetes, hypertension and hypercholesterolemia.²³ Muscular fitness has been shown to be inversely associated with WC, TG and fasting glucose.^{24–25} We showed that running performance was negatively correlated with the incidence of MS, WC, TG and fasting glucose and positively correlated with HDL level. The performance of sit-ups and push-ups in 2 min was negatively correlated with SBP, TG and fasting glucose and positively correlated with HDL level.

However, our study had some limitations. First, there was no information on personal dietary habits, including dining out. Although the food in the military was supplied by the

Non-staple Food Supply Station, externally supplied food eaten by the participants was not taken into consideration. Second, subgroup analyses in women were underpowered because of their small numbers. Hence, the effects of physical fitness on women require further investigation. Third, there was no adjustment for potential confounders, such as mental illness (eg, work stress, depression or post-traumatic stress disorder). The mental condition was not included in the regular physical record. However, milder conditions did not affect PFT receipt, and those with more severe conditions requiring regular medical attention were excluded from the study. Fourth, information on leisure-time physical activities, such as sports club participation or other activities, was not included. However, it is less likely that when the PFT requirement was introduced, the soldiers were involved in more leisure-time physical activities in addition to more rigorous training. Rather, a reduction in leisure-time activities may have been more probable. If so, the effect of the PFT might have been in favour of the null hypothesis. Data on these factors are needed to further evaluate the influence of physical fitness on MS in the future.

CONCLUSION

Our study revealed that the reformed physical fitness programme and the stricter eligibility criteria of the PFT were inversely associated with MS incidence among personnel in the armed forces. Better physical fitness performance can protect against MS and associated conditions. Clinicians should encourage sedentary military personnel to be more physically active to improve their physical fitness and reduce the risk of MS development.

Contributors This study was designed, directed and coordinated by Che-Fu Chang and Yue-Liang Guo, as the principal investigator, provided conceptual and technical guidance for all aspects of the project. Ching-Huang Lai and Che-Fu Chang performed and analysed the data. Yi-Chang Wu and Po-Chung Chen suggested and commented on the design of the study. The manuscript was written by Che-Fu Chang and Yue-Liang Guo and started on by all authors.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent for publication Not required.

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study was approved by the Institutional Review Board of the Tri-Service General Hospital (TSGHIRB No.: 1-105-05-104).

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available. Data are obtained from a repository and are not publicly available.

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Table 1. Baseline characteristics of military personnel based on the 2011 annual health check-up (N = 1,720)

Variable	Men	Mean \pm SD	Women	Mean \pm SD
	n = 1,462 (%)		n = 258 (%)	
Age (years)		35.23 \pm 4.46		35.20 \pm 3.10
<35	782 (53.40)		108 (41.86)	
\geq 35	680 (46.52)		150 (58.14)	
Current smoking				
Yes	357 (24.4)		5 (1.9)	
No	1,105 (75.6)		253 (98.1)	
Current alcohol drinking				
Yes	442 (30.23)		10 (3.87)	
No	1,020 (69.77)		248 (96.13)	
Body mass index		25.33 \pm 3.29		22.73 \pm 3.34
<24	951 (65.05)		177 (68.60)	
\geq 24	511 (34.95)		81 (31.40)	
Baseline measurements				
Systolic blood pressure (mmHg)		128.27 \pm 13.71		118.13 \pm 14.15
\geq 130	678 (46.37)		59 (22.89)	
<130	784 (53.63)		199 (77.11)	
Diastolic blood pressure (mmHg)		79.56 \pm 9.56		72.65 \pm 9.51
\geq 85	390 (26.68)		25 (9.69)	

<85	1,072 (73.32)	233 (90.31)
Waist circumference (cm)	84.80 ± 8.22	74.44 ± 8.71
Abnormal (Men ≥90, women ≥80)	377 (25.7)	68 (26.4)
Normal (Men <90, women <80)	1,085 (74.3)	190 (73.6)
Triglycerides (mg/dL)	120.95 ± 84.94	79.08 ± 43.57
≥150	338 (23.1)	22 (8.5)
<150	1,124 (76.9)	236 (91.5)
Fasting glucose (mg/dL)	91.52 ± 9.98	88.15 ± 7.64
≥100	164 (11.2)	14 (5.4)
<100	1,298 (88.8)	244 (94.6)
HDL-C (mg/dL)	52.36 ± 12.52	66.80 ± 15.06
Abnormal (Men <40, women <50)	224 (7.0)	28 (10.9)
Normal (Men ≥40, women ≥50)	1,238 (93.0)	230 (89.1)
No. of metabolic syndrome factors		
0	477 (32.6)	141 (54.7)
1	491 (33.6)	70 (27.1)
2	270 (18.5)	25 (9.69)
≥3	224 (15.3)	22 (8.52)

SD: standard deviation, *HDL-C*: high-density lipoprotein cholesterol