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ORIGINAL RESEARCH

Establishing cutoff points for health-related fitness and metabolic risk factors in middle-aged men with metabolic syndrome

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Abstract

Background: This study aimed to establish threshold values for health-related fitness and metabolic disease factors to provide practical evidence-based guidelines for the prevention of metabolic syndrome in middle-aged men. **Methods**: A total of 323 participants were classified into a metabolic syndrome group and a non-Metabolic syndrome (non-MetS) group based on established diagnostic criteria. Health-related fitness parameters, including muscular strength, muscular endurance, cardiorespiratory fitness and flexibility, as well as metabolic disease markers such as waist circumference, blood pressure and blood lipid profiles, were compared between groups using an independent *t*-test. Additionally, receiver operating characteristic curve analysis was employed to determine threshold values predictive of metabolic syndrome risk. **Results**: The metabolic syndrome group exhibited significantly higher body weight, body fat percentage and body mass index compared to the non-MetS group. Furthermore, metabolic disease markers, including waist circumference, systolic blood pressure, diastolic blood pressure, triglycerides, low-density lipoprotein cholesterol and hemoglobin A1c , were significantly elevated in the metabolic syndrome group. Conversely, health-related fitness levels were significantly lower. Receiver operating characteristic (ROC) curve analysis identified the following threshold values for health-related fitness: maximal oxygen consumption of 39.45 mL/kg/min, relative grip strength of 57.88% (left) and 60.36% (right), 29.5 repetitions for sit-ups, 20.5 repetitions for push-ups, 33.5 repetitions for side steps and a vertical jump height of 34.5 cm. The threshold values for metabolic disease markers were determined as follows: waist circumference $\geq$87.5 cm, systolic blood pressure $\geq$130.5 mmHg, diastolic blood pressure $\geq$77.5 mmHg, triglycerides $\geq$156.5 mg/dL, HbA1c $\geq$5.45% and high-density lipoprotein cholesterol $\leq$44.5 mg/dL. **Conclusions**: This study highlights the importance of maintaining metabolic markers below risk thresholds and enhancing health-related fitness to prevent metabolic syndrome in middle-aged men. Targeted exercise is key, and future studies should verify these thresholds across populations and assess long-term outcomes.

Keywords

Metabolic syndrome; Middle-aged men; Health-related fitness; Metabolic dieases factor; ROC curve analysis

1. Introduction

Metabolic syndrome (MetS) is characterized by the coexistence of at least three metabolic abnormalities, including central obesity, hypertension, impaired fasting glucose, hypertriglyceridemia and low high-density lipoprotein-cholesterol (HDL-C) [1]. MetS, driven by insulin resistance and chronic inflammation, significantly increases the risk of type 2 diabetes mellitus (T2DM) and cardiovascular disease (CVD), as well as overall mortality. Consequently, it has been recognized as a critical factor in middle-aged health management [2–4].

In recent years, the prevalence of MetS has been steadily rising in South Korea, particularly among men, where the incidence accelerates rapidly from their 30s onward [5, 6]. Reports indicate that the prevalence rate increased from 26.6% in 2013 to 36.8% in 2022, reflecting a nearly 10% rise over the past decade [7]. This trend is largely attributed to lifestyle changes, including the adoption of Westernized dietary patterns, reduced physical activity, chronic stress, and insufficient sleep [8].

MetS is increasingly recognized not merely as a cluster of metabolic abnormalities but as a multifactorial health issue that markedly elevates the risk of CVD and metabolic disorders [9–11]. Individuals with MetS are more susceptible to atherosclerosis, coronary artery disease (CAD), and stroke, with a significantly higher overall mortality rate [11, 12]. Given the strong association between MetS progression and lifestyle factors, numerous studies have demonstrated that both quantitative and qualitative exercise interventions play a crucial role in improving metabolic function [13, 14]. Specifically, enhancing cardiorespiratory fitness (CRF) and muscular strength has been shown to improve insulin sensitivity and normalize lipid metabolism, thereby contributing to the prevention and management of MetS [15, 16].

Previous studies investigating the relationship between MetS and physical fitness have consistently reported that individuals without MetS exhibit significantly higher levels of physical fitness than those with the condition. Key factors such as muscular strength, muscular endurance and aerobic endurance have been identified as protective elements against metabolic disorders [17–19]. However, existing research has primarily focused on demonstrating that higher fitness levels confer health benefits, without establishing concrete threshold values that define the minimum fitness level required for MetS prevention and management. In other words, while the association between fitness and MetS risk is well established, there remains a critical gap in identifying precise cutoff values that can serve as objective health guidelines.

Deriving cut-off values using Receiver Operating Characteristic (ROC) curve analysis provides an objective approach to determining the threshold at which specific physical fitness variables best discriminate between individuals with and without metabolic syndrome. The ROC curve is widely employed to evaluate the diagnostic accuracy of tools predicting chronic conditions such as diabetes and cardiovascular disease, offering both visual and quantitative assessments of predictive performance. The Area Under the Curve (AUC) serves as a key indicator of diagnostic capability and is interpreted as follows: non-informative (AUC = 0.5), poor accuracy ($0.5 < \text{AUC} \leq 0.7$), moderate accuracy ($0.7 < \text{AUC} \leq 0.9$), high accuracy ($0.9 < \text{AUC} < 1$) and perfect accuracy (AUC = 1) [20]. Thus, ROC-based analysis surpasses mere correlation assessment, establishing evidence-based thresholds that can guide clinical and public health decision-making.

The present study aims to establish threshold values for health-related fitness factors (muscular strength, muscular endurance, flexibility and cardiorespiratory endurance) and metabolic disease markers (waist circumference (WC), systolic blood pressure (SBP), diastolic blood pressure (DBP), triglycerides (TG), LDL-C, HDL-C, *etc.*) to provide objective criteria for health management. To achieve this, we will conduct a comparative analysis of health-related fitness and metabolic disease factors between middle-aged men (aged 30–60) with and without MetS. Furthermore, by deriving predictive threshold values for MetS occurrence, this study seeks to contribute to the development of practical health management guidelines. The findings are expected to offer scientific evidence for the prevention of MetS and the promotion of physical fitness in middle-aged men, as well as facilitate the development of personalized health management strategies and exercise prescriptions.

2. Methods

2.1 Participants

This study analyzed adult men aged 35 to 64 who underwent health examinations at the Korea Institute of Sport Science's National Fitness Center between 2022 and 2024, following the complete lifting of all COVID-19 social distancing measures. The classification of middle adulthood varies across international and domestic standards. This study incorporated both demographic frameworks and sociocultural perceptions to define its target population. Caspersen, Pereira, and Curran [21] categorized adults in their study on physical activity patterns in the United States into young adults (18–34 years), middle-aged adults (30–64 years), and older adults (65 years and older). They highlighted that the middle-age period is marked by a decline in physical function and increased incidence of chronic diseases. Furthermore, a study by Lee [22] found that the general Korean public tends to perceive age 35 as the beginning of middle adulthood, with 65 years considered the threshold for older adulthood. Based on these international standards and sociocultural insights, this study focused on analyzing the physical fitness characteristics and health indicators of individuals within the middle-age demographic.

Participants with missing essential data or those with medical conditions that could potentially confound the study results were excluded. A total of 323 participants were included in the final analysis, categorized as follows: 86 participants in their 30s, 96 in their 40s, 105 in their 50s and 36 in their 60s. Although the sample size in this study (n = 323) does not meet the threshold of 728 participants recommended by Negida *et al.* [23] for area under the ROC curve (AUC)-based diagnostic accuracy studies, previous literature supports that a sample size of approximately 300 can be sufficient to ensure statistical reliability in analyses utilizing sensitivity and specificity [24–26]. In particular, the present study was designed based on predefined assumptions regarding disease prevalence, anticipated sensitivity and specificity, and effect size. Under these parameters, the chosen sample size of 323 is considered adequate to ensure both statistical validity and diagnostic reliability in ROC curve-based evaluations.

All research procedures followed the principles of the Declaration of Helsinki and were approved by the Institutional Review Board (2025-01-009). Data were retrospectively collected from health examination records after participant selection.

2.2 Analysis variables

2.2.1 Anthropometric measurements

Anthropometric data were collected by measuring body weight (kg) and height (cm) to one decimal place while participants wore light clothing. Body composition parameters, including muscle mass, body fat mass, and body fat percentage, were assessed using bioelectrical impedance analysis (BIA) with the InBody 770 system (InBody, InBody 770 system, Seoul, Korea).

2.2.2 Physical fitness factors

Physical fitness was assessed using standard protocols at the National Fitness Center, which included sit-ups, push-ups, sit-and-reach tests, relative grip strength, side steps and vertical jumps. The number of repetitions for the sit-up and push-up tests was recorded as the maximum number completed within 1 minute, while the side-step test was measured as the maximum number of repetitions completed within 20 seconds. In addition, cardiorespiratory endurance and muscular strength were measured using gas analysis and isokinetic strength testing, respectively. Cardiorespiratory endurance was evaluated using a treadmill-based breath-by-breath gas exchange analysis system (Cosmed, Quark CPET, Rome, Italy). The Bruce Protocol was applied to determine maximal oxygen uptake. Muscular strength was assessed using an isokinetic dynamometer (Biodex Medical Systems, Biodex System 3, New York, NY, USA) to measure knee extensor and flexor muscle function. Peak torque relative to body weight (Peak Torque/BW) was recorded at an angular velocity of 60°/s, with participants performing three maximal extension and flexion repetitions. All physical fitness assessments were conducted using standardized protocols applied uniformly across all age groups. The measurements were performed by trained assessment professionals from National Fitness Center, under the supervision of the study's principal investigator.

2.2.3 Metabolic disease factors

Metabolic disease markers included systolic blood pressure (SBP), diastolic blood pressure (DBP), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), triglycerides (TG) and hemoglobin A1c (HbA1c). Blood samples were obtained via venipuncture from the antecubital vein after an 8-hour fasting period. A trained clinical laboratory technician collected 10 mL of blood, which was stored at room temperature for 15 to 30 minutes before centrifugation at 3000 rpm for subsequent biochemical analysis.

2.2.4 Definition and assessment of metabolic syndrome risk factors

In this study, metabolic syndrome (MetS) was defined according to the criteria established by the National Cholesterol Education Program Adult Treatment Panel III (NCEP-ATP III) and the waist circumference standards for Koreans proposed by the Korean Society for the Study of Obesity [27, 28]. Participants were classified as having MetS if they met at least three of the criteria outlined in Table 1.

2.3 Data analysis

All statistical analyses were conducted using SPSS software (version 25.0, IBM, Chicago, IL, USA). Descriptive statistics, including mean and standard deviation, were calculated. Prior to analysis, normality was assessed using skewness and kurtosis values. To examine the relationship between age groups, metabolic syndrome risk factors, and MetS prevalence, a chi-square test was performed. Differences in anthropometric characteristics, physical fitness, and metabolic disease markers between the MetS and non-MetS groups were analyzed using an independent *t*-test. Correlation analysis was conducted to determine associations between physical fitness and metabolic disease markers. To identify threshold values and assess predictive validity, a Receiver Operating Characteristic (ROC) curve analysis was conducted. The optimal cutoff point was determined as the value where the sum of sensitivity and specificity was maximized. The statistical significance level was set at $\alpha = 0.05$ for all analyses.

TABLE 1. Diagnostic criteria for metabolic syndrome.

Risk factors	Criteria for diagnosis
WC	≥90 cm
BP	SBP ≥130 mmHg, DBP ≥85 mmHg
HDL-C	≤40 mg/dL
TG	≥150 mg/dL
HbA1c	≥6.5%

WC: Waist Circumference; BP: Blood Pressure; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; HDL-C: High-Density Lipoprotein-Cholesterol; TG: Triglyceride; HbA1c: Hemoglobin A1c.

3. Results

3.1 Relationship between metabolic syndrome and metabolic disease risk factors

The results of the chi-square analysis examining the relationship between MetS, age and metabolic disease risk factors are presented in Table 2. WC showed a statistically significant association with MetS classification ($p < 0.001$). In the non-MetS group, a higher proportion of individuals had a WC ≤90 cm, whereas in the MetS group, a higher proportion had a WC >90 cm. SBP was also significantly associated with MetS classification ($p < 0.001$). In the non-MetS group, the majority had an SBP ≤130 mmHg, whereas in the MetS group, a greater proportion had an SBP >130 mmHg. DBP demonstrated a statistically significant relationship with MetS classification ($p < 0.001$). The non-MetS group predominantly had a DBP ≤85 mmHg, while the MetS group had a higher proportion of individuals with a DBP >85 mmHg. HDL-C was significantly associated with MetS classification ($p < 0.001$). In the non-MetS group, the proportion of individuals with HDL-C ≥40 mg/dL was higher, whereas in the MetS group, a greater proportion had HDL-C <40 mg/dL. TG also showed a statistically significant association with MetS classification ($p < 0.001$). In the non-MetS group, the majority had TG levels ≤150 mg/dL, whereas in the MetS group, a larger proportion had TG levels >150 mg/dL. HbA1c exhibited a statistically significant relationship with MetS classification ($p < 0.001$). In the non-MetS group, a higher proportion of individuals had an HbA1c level ≤6.5%, whereas in the MetS group, a relatively higher proportion had an HbA1c level >6.5%.

TABLE 2. Associations between metabolic risk factors and metabolic syndrome status.

	Non-MetS (n = 197)	MetS (n = 126)	χ^2	p
Age (yr)				
30s	55 (27.9)	31 (24.6)	6.525	0.089
40s	50 (25.4)	46 (36.5)		
50s	65 (33.0)	40 (31.7)		
60s	27 (13.7)	9 (7.1)		
WC (cm)				
<90	172 (87.3)	43 (34.1)	97.660	<0.001
≥90	25 (12.7)	83 (65.9)		
SBP (mmHg)				
<130	146 (74.1)	23 (18.3)	96.117	<0.001
≥130	51 (25.9)	103 (81.7)		
DBP (mmHg)				
<85	183 (92.9)	58 (46.0)	89.093	<0.001
≥85	14 (7.1)	68 (54.0)		
HDL-C (mg/dL)				
<40	25 (12.7)	59 (46.8)	46.533	<0.001
≥40	172 (87.3)	67 (53.2)		
TG (mg/dL)				
<150	146 (74.1)	26 (20.6)	88.280	<0.001
≥150	51 (25.9)	100 (79.4)		
HbA1c (%)				
<6.5	196 (99.5)	113 (89.7)	17.835	<0.001
≥6.5	1 (0.5)	13 (10.3)		

Data shown as number (%).
WC: Waist Circumference; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; HDL-C: High-Density Lipoprotein-Cholesterol; TG: Triglyceride; HbA1c: Hemoglobin A1c; MetS: Metabolic syndrome.

3.2 Differences in characteristics based on the presence of metabolic syndrome

The results of the analysis of differences in physical characteristics according to the presence of MetS are presented in Table 3. The findings indicate that the MetS group had significantly higher values than the non-MetS group for body weight ($p < 0.001$), lean body mass ($p < 0.001$), fat mass ($p < 0.001$), BMI ($p < 0.001$), body fat percentage ($p < 0.001$) and abdominal obesity ratio ($p < 0.001$).

3.3 Differences in physical fitness and metabolic disease risk factors based on the presence of metabolic syndrome

The analysis of differences in physical fitness and metabolic disease risk factors between the MetS and non-MetS groups revealed significant disparities. In terms of physical fitness, the non-MetS group exhibited superior performance compared to the MetS group in the following tests: sit-ups ($p < 0.001$), push-ups ($p < 0.001$), sit-and-reach test ($p < 0.001$), left handgrip strength ($p < 0.001$), right handgrip strength ($p < 0.001$), sidestep test ($p = 0.030$), vertical jump ($p < 0.001$), exercise duration ($p < 0.001$), maximal oxygen consumption (VO_2max) ($p < 0.001$) and knee flexion peak torque/body weight (FXBW) ($p = 0.034$), all of which showed statistically significant differences. In contrast, the MetS group demonstrated significantly higher values in metabolic disease risk factors. WC ($p < 0.001$), SBP ($p < 0.001$), DBP ($p < 0.001$), TG ($p < 0.001$) and HbA1c ($p < 0.001$) were all significantly elevated in the MetS group. Conversely, HDL-C was significantly higher in the non-MetS group. These findings highlight the strong relationship between lower physical fitness levels and the presence of metabolic syndrome, emphasizing the importance of maintaining physical fitness to mitigate metabolic disease risks (Table 4).

3.4 Correlation analysis between physical fitness and metabolic disease risk factors

The results of the correlation analysis between physical fitness factors and metabolic disease risk factors are presented in Table 5. Physical fitness factors exhibited a negative correlation with metabolic disease risk factors, while HDL-C showed a positive correlation.

TABLE 3. Physical characteristics by metabolic syndrome status.

	Non-MetS (n = 197)	MetS (n = 126)	*t*	*p*
Height (cm)	172.08 ± 5.78	171.55 ± 5.32	0.840	0.402
Weight (kg)	72.52 ± 8.76	80.88 ± 11.38	−7.027	<0.001
LBM (kg)	55.64 ± 5.92	59.29 ± 7.51	−4.617	<0.001
Body fat (%)	16.85 ± 4.21	21.57 ± 5.10	−8.671	<0.001
BMI (kg/m^2)	24.46 ± 2.43	27.43 ± 3.17	−8.949	<0.001
BFP (%)	23.00 ± 3.98	26.42 ± 3.69	−7.747	<0.001
WHR	0.91 ± 0.05	0.95 ± 0.04	−6.796	<0.001

Data shown as Mean ± S.D (standard deviation).
LBM: Lean Body Mass; BMI: Body Mass Index; BFP: Body Fat Percentage; WHR: Waist to Hip Ratio; MetS: Metabolic syndrome.

TABLE 4. Differences in physical fitness and metabolic risk factors by metabolic syndrome status.

	Non-MetS (n = 197)	MetS (n = 126)	*t*	*p*
Sit-up (times)	30.35 ± 7.08	24.15 ± 8.02	7.441	<0.001
Push-up (times)	24.40 ± 11.41	18.51 ± 9.47	4.830	<0.001
Sit and reach (cm)	7.07 ± 8.089	3.40 ± 7.86	4.015	<0.001
L-RGS (%)	62.14 ± 10.15	55.17 ± 9.14	6.259	<0.001
R-RGS (%)	64.34 ± 10.05	55.83 ± 10.50	7.295	<0.001
Sidestep (times)	33.39 ± 5.70	31.98 ± 5.59	2.185	0.030
Vertical jump (cm)	36.32 ± 8.18	32.94 ± 6.76	3.865	<0.001
Exercise time (min)	561.43 ± 91.28	501.15 ± 87.03	5.894	<0.001
VO_2max (mL/kg/min)	41.89 ± 5.64	36.96 ± 5.53	7.733	<0.001
HRmax (bpm)	171.03 ± 13.86	168.08 ± 15.27	1.795	0.074
EXBW (%)	181.54 ± 31.55	178.58 ± 35.02	0.786	0.432
FXBW (%)	84.50 ± 17.28	80.20 ± 18.46	2.124	0.034
WC (cm)	83.80 ± 6.16	91.59 ± 8.10	−9.220	<0.001
SBP (mmHg)	121.78 ± 10.85	135.28 ± 9.93	−11.487	<0.001
DBP (mmHg)	73.16 ± 7.94	83.13 ± 8.56	−10.683	<0.001
TC (mg/dL)	195.87 ± 34.33	201.48 ± 32.43	−1.462	0.145
HDL-C (mg/dL)	49.24 ± 9.91	42.94 ± 9.43	5.681	<0.001
TG (mg/dL)	122.73 ± 57.87	202.21 ± 71.42	−10.484	<0.001
HbA1c (%)	5.36 ± 0.44	5.69 ± 0.51	−6.090	<0.001

Data shown as Mean ± S.E (standard error).
L-RGS: Left-Relative Grip Strength; R-RGS: Right-Relative Grip strength; VO_2max: maximal oxygen uptake; HRmax: Heart Rate maximum; EXBW: Knee Extension peak torque/Body Weight; FXBW: Knee Flexion peak torque/Body Weight; WC: Waist Circumference SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; TC: total cholesterol; HDL-C: High-Density Lipoprotein-Cholesterol; TG: Triglyceride; HbA1c: Hemoglobin A1c; MetS: Metabolic syndrome.

3.5 Threshold values of metabolic syndrome risk factors for identifying metabolic syndrome

The threshold values of metabolic disease risk factors for identifying metabolic syndrome were determined using ROC curve analysis. The results indicated that the optimal cutoff for waist circumference was 87.5 cm, with a sensitivity of 71.4% and specificity of 76.1%. The threshold for SBP was 130.5 mmHg (sensitivity: 75.4%, specificity: 78.7%), while the threshold for DBP was 77.5 mmHg (sensitivity: 73.8%, specificity: 72.6%). The TG threshold was 156.5 mg/dL (sensitivity: 75.4%, specificity: 77.7%). Additionally, the optimal HDL-C cutoff was 44.5 mg/dL, with a sensitivity of 64.7% and specificity of 66.7% (Table 6, Fig. 1).

TABLE 5. Correlation between physical fitness and metabolic risk factor.

	WC	SBP	DBP	HDL-C	TG	HbA1c
Sit-up	−0.375**	−0.240**	−0.236**	0.161**	−0.117*	−0.387**
Push-up	−0.373**	−0.151**	−0.154**	0.137*	−0.111*	−0.244**
Sit and reach	−0.176**	−0.059	−0.067	0.065	−0.146**	−0.076
L-RGS	−0.487**	−0.214**	−0.127*	0.069	−0.155**	−0.155**
R-RGS	−0.509**	−0.224**	−0.188**	0.098	−0.170**	−0.195**
Sidestep	−0.166**	−0.024	−0.066	0.131*	−0.048	−0.221**
Vertical jump	−0.238**	−0.092	−0.098	0.094	−0.051	−0.184**
Exercise time	−0.314**	−0.132*	−0.127*	0.120*	−0.212**	−0.233**
VO_2max	−0.450**	−0.148**	−0.169**	0.191**	−0.246**	−0.300**
FXBW	0.145**	−0.036	−0.069	0.058	0.018	−0.104

**p* < 0.05, ***p* < 0.01.

L-RGS: Left-Relative Grip Strength; R-RGS: Right-Relative Grip strength; VO_2max: maximal oxygen uptake; FXBW: Knee Flexion peak torque/Body Weight; WC: Waist Circumference; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; HDL-C: High-Density Lipoprotein-Cholesterol; TG: Triglyceride; HbA1c: hemoglobin A1c.

TABLE 6. ROC curve-based cutoff analysis of metabolic risk factors for metabolic syndrome.

	Cut-off	AUC	95% CI	Sensitivity	Specificity	*p*
WC (cm)	87.5	0.782	0.729–0.836	71.4%	76.1%	<0.001
SBP (mmHg)	130.5	0.821	0.776–0.867	75.4%	78.7%	<0.001
DBP (mmHg)	77.5	0.807	0.757–0.857	73.8%	72.6%	<0.001
TG (mg/dL)	156.5	0.815	0.766–0.863	75.4%	77.7%	<0.001
HbA1c (%)	5.45	0.687	0.629–0.745	59.5%	64.0%	<0.001
HDL-C (mg/dL)	44.5	0.706	0.646–0.767	64.7%	66.7%	<0.001

AUC: Area Under the Curve; CI: Confidence Interval; WC: Waist Circumference; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; TG: Triglyceride; HbA1c: hemoglobin A1c; HDL-C: High-Density Lipoprotein-Cholesterol.

3.6 Threshold values of physical fitness factors for identifying metabolic syndrome

The threshold values of physical fitness factors for identifying metabolic syndrome were also analyzed. The optimal cutoff for sit-ups was 29.5 repetitions (sensitivity: 73.1%, specificity: 65.9%), while for push-ups, it was 20.5 repetitions (sensitivity: 50.8%, specificity: 67.5%). The threshold for flexibility, measured by the sit-and-reach test, was 5.12 cm (sensitivity: 58.4%, specificity: 62.7%). The left and right handgrip strength thresholds were 57.88% (sensitivity: 64.0%, specificity: 65.1%) and 60.36% (sensitivity: 66.0%, specificity: 66.7%), respectively. The cutoff for the sidestep test was 33.5 repetitions (sensitivity: 53.8%, specificity: 54.0%), and for vertical jump, it was 34.5 cm (sensitivity: 56.3%, specificity: 58.7%). The exercise duration threshold was 526.5 seconds (sensitivity: 62.9%, specificity: 65.1%), while the optimal cutoff for maximal oxygen consumption (VO_2max) was 39.45 mL/kg/min (sensitivity: 65.0%, specificity: 67.5%) (Table 7, Fig. 2).

4. Discussion

This study aims to analyze the differences in health-related fitness and metabolic disease factors based on the presence of metabolic syndrome in middle-aged men and to derive threshold values for predicting metabolic syndrome using ROC curve analysis. Metabolic syndrome is defined as the presence of three or more risk factors, including abdominal obesity, hypertension, hyperglycemia, hypertriglyceridemia and low HDL-C levels, which serve as major risk factors for cardiovascular and metabolic diseases [29]. Even if the individual risk factors do not reach the threshold requiring medication, their simultaneous presence significantly increases mortality rates and the incidence of cardiovascular and cerebrovascular diseases [9]. According to data from the National Health Insurance Service of Korea, the prevalence of metabolic syndrome increased from 22.6% in 2013 to 30.4% in 2018 but subsequently decreased to 22.6% in 2023 [30–32]. In terms of age-specific prevalence, data from 2023 show that 16.7% of men aged 35 to 39 years were affected, which is approximately five times higher than the prevalence observed in women of the same age group (3.4%). The prevalence among men continued to increase with age, reaching 36.7% in those aged 65 to 69 years [32]. These findings indicate that middle-aged men represent a population group particularly vulnerable to metabolic syndrome, highlighting the need for targeted preventive interventions. These statistics further underscore the importance of proactive health management to improve both physical and mental well-being during this critical stage

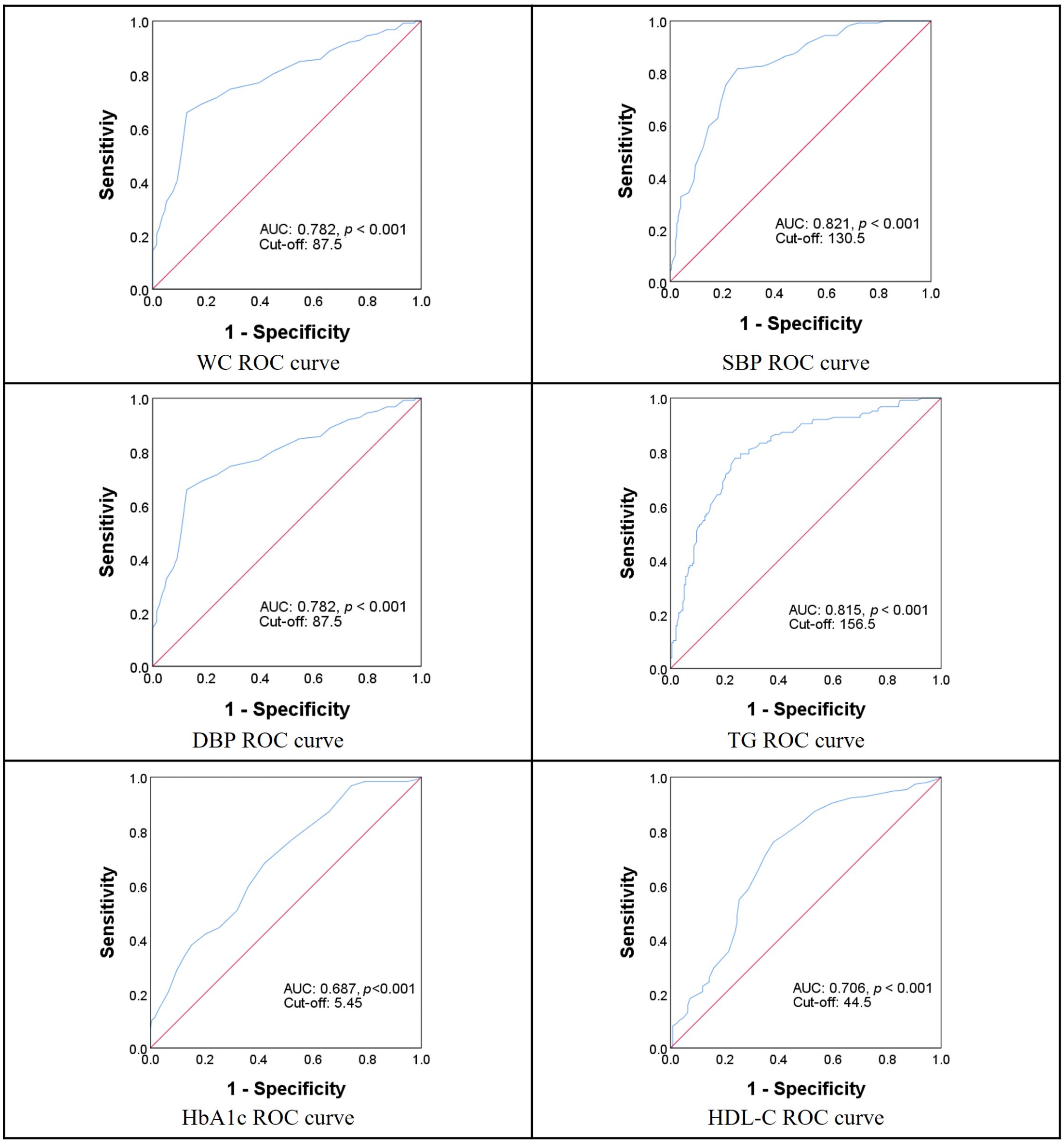

FIGURE 1. Graph of ROC curve-based cutoff analysis of metabolic risk factors for metabolic syndrome. AUC: Area Under the Curve; WC: Waist Circumference; ROC: receiver operating characteristic; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; TG: Triglyceride; HbA1c: hemoglobin A1c; HDL-C: High-Density Lipoprotein-Cholesterol.

TABLE 7. ROC curve-based cutoff analysis of physical fitness factors for metabolic syndrome.

	Cut-off	AUC	95% CI	Sensitivity	Specificity	*p*
Sit-up (times)	29.50	0.728	0.671–0.784	73.1	65.9	<0.001
Push-up (times)	20.50	0.651	0.591–0.712	50.8	67.5	<0.001
Sit and reach (cm)	5.12	0.632	0.570–0.693	58.4	62.7	<0.001
L-RGS (%)	57.88	0.691	0.633–0.750	64.0	65.1	<0.001
R-RGS (%)	60.36	0.722	0.665–0.779	66.0	66.7	<0.001
Sidestep (times)	33.50	0.568	0.505–0.632	53.8	54.0	<0.001
Vertical jump (cm)	34.50	0.619	0.557–0.680	56.3	58.7	<0.001
Exercise time (min)	526.50	0.680	0.621–0.739	62.9	65.1	<0.001
VO_2max (mL/kg/min)	39.45	0.729	0.673–0.785	65.0	67.5	<0.001
FXBW (%)	80.25	0.564	0.499–0.629	52.3	52.4	<0.001

AUC: Area Under the Curve; CI: Confidence Interval; L-RGS: Left-Relative Grip Strength; R-RGS: Right-Relative Grip strength; VO_2max: maximal oxygen uptake; FXBW: Knee Flexion peak torque/Body Weight.

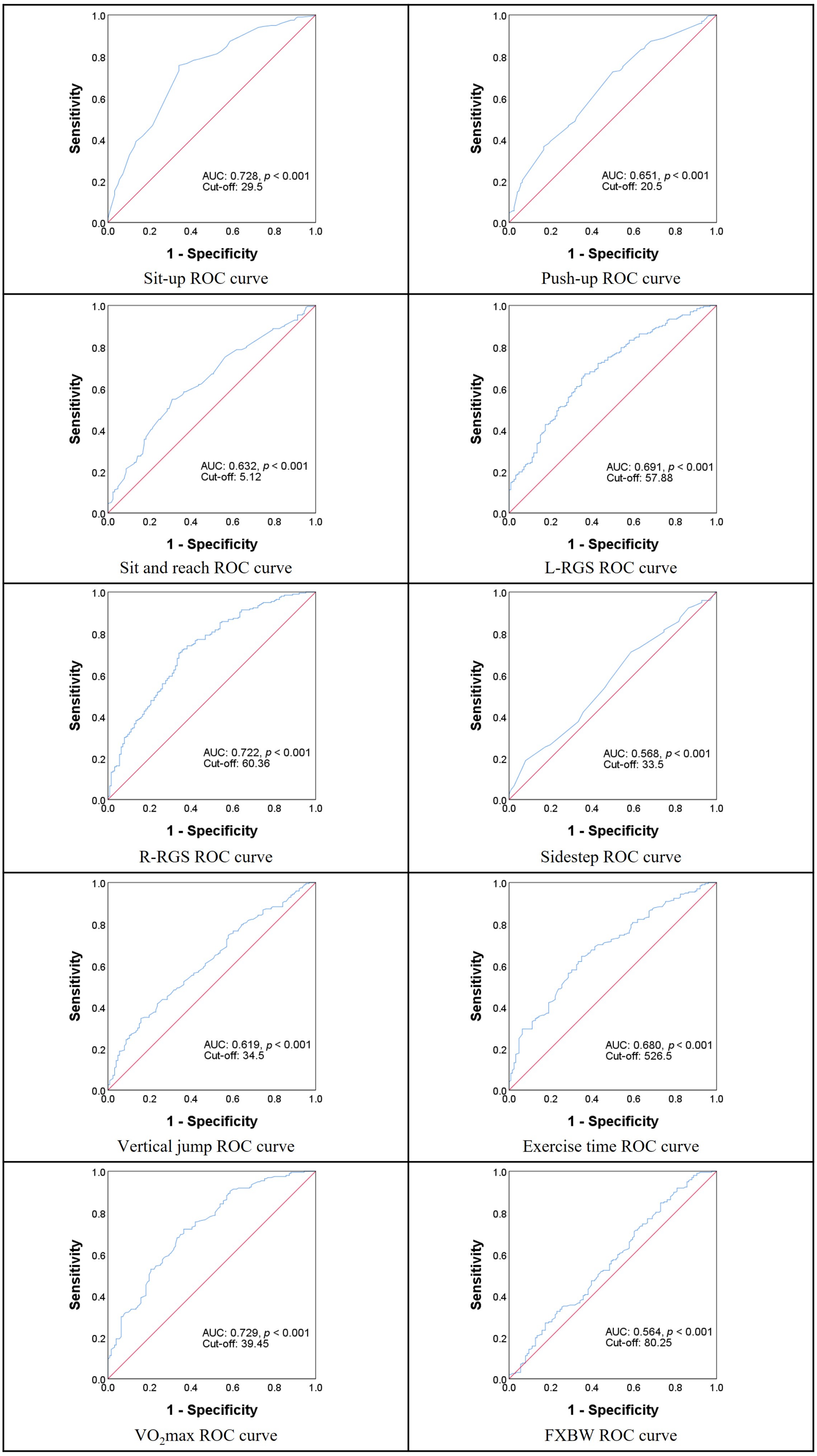

FIGURE 2. Graph of ROC curve-based cutoff analysis of physical fitness factors for metabolic syndrome. AUC: Area Under the Curve; ROC: receiver operating characteristic; L-RGS: Left-Relative Grip Strength; R-RGS: Right-Relative Grip strength; VO_2max: maximal oxygen uptake; FXBW: Knee Flexion peak torque/Body Weight.

of life. Regular physical activity has been reported to enhance cardiorespiratory endurance and muscular strength while reducing the incidence of metabolic syndrome [33]. A review of previous research on the relationship between physical fitness and metabolic syndrome suggests that individuals with a VO_2max below 28.9 mL/kg/min have a 30% higher prevalence of metabolic syndrome compared to those with a VO_2max above 35.7 mL/kg/min [34]. Additionally, Atlantis *et al.* [35] reported that individuals with the lowest muscle mass have up to a 3.34 times higher prevalence of metabolic syndrome than those with the highest muscle mass, while those with the weakest grip strength are 2.15 times more likely to develop metabolic syndrome. These findings indicate that lower physical fitness levels increase the risk of metabolic syndrome, emphasizing the necessity of improving physical fitness through regular exercise for its prevention and management [33].

Using ROC curve analysis, this study derived threshold values for health-related fitness factors associated with metabolic syndrome prevention. The results indicate that the threshold for VO_2max is 39.45 mL/kg/min, while the relative grip strength thresholds are 57.88% for the left hand and 60.36% for the right hand. Additionally, performance thresholds were identified as 5.12 cm for the sit-and-reach test, 29.5 repetitions for sit-ups, 20.5 repetitions for push-ups, 33.5 repetitions for the side-step test, and 34.5 cm for the standing vertical jump. These levels of performance were found to be significantly associated with the prevention of metabolic syndrome. However, the ROC curve analysis for the side-step and FXBW tests yielded AUC values of 0.568 and 0.564, respectively. In a systematic review of ROC analysis, Hajian-Tilaki & Karimollah [36] stated that an AUC value below 0.6 indicates poor discriminative ability, and such variables are generally considered unsuitable for clinical or public health decision-making. Therefore, the diagnostic utility of these two variables appears to be limited, suggesting that they may not serve as effective indicators for predicting or distinguishing the presence of metabolic syndrome. Meanwhile, according to the certification criteria of the National Fitness Award 100 program provided by the Korea Sports Promotion Foundation, individuals are classified into fitness grades based on five key health-related fitness components. Specifically, individuals scoring above the 30th percentile are awarded grade 3, above the 50th percentile are awarded grade 2, and above the 70th percentile are awarded grade 1. For grade 3, the standards are set at 37.2 mL/kg/min for cardiorespiratory fitness, 51.1% for relative grip strength, 33 repetitions for sit-ups, and less than or equal to 4.6 cm for the sit-and-reach flexibility test. Taken together, the cut-off values for key physical fitness factors identified in this study for the prevention of metabolic syndrome appear to be generally higher than the third-grade criteria established by the National Fitness Award 100 program. Notably, both cardiorespiratory fitness and relative grip strength demonstrated higher thresholds for the prevention of metabolic syndrome compared to the general fitness standards of the national certification program. This suggests that more stringent fitness management may be necessary when targeting metabolic disease prevention, beyond the levels defined for general health maintenance. Furthermore, certain fitness components such as push-ups, side-steps and standing vertical jump, which were identified as relevant in this study, are not currently included in the official certification criteria of the National Fitness Award 100. These findings indicate that such additional fitness measures may also play a significant role in preventing metabolic disorders and warrant consideration in future health-related fitness guidelines. These findings highlight the importance of incorporating both aerobic exercise and resistance training to improve muscular function in metabolic syndrome prevention and provide valuable baseline fitness criteria for its management.

WC is a key indicator of abdominal obesity, with increases in WC being strongly associated with insulin resistance, cardiovascular disease, and a heightened risk of metabolic syndrome [37–39]. Excessive adipose tissue accumulation leads to the secretion of adipocytokines such as adiponectin, resistin and leptin, which are linked to insulin resistance, inflammatory responses, and atherosclerosis. Therefore, an increase in WC represents a more severe health risk than simple weight gain [40–42]. Blood pressure is another critical factor closely linked to metabolic syndrome, classified into essential hypertension, with no identifiable cause, and secondary hypertension, which results from specific underlying conditions [43]. Elevated blood pressure increases the risk of cardiovascular disease, and individuals with uncontrolled hypertension have an even higher risk of developing metabolic syndrome [44, 45]. Previous studies have shown that a single exercise session at 60% of HRmax (Heart Rate maximum) can reduce blood pressure and enhance vascular elasticity in hypertensive individuals [46, 47]. Dyslipidemia is defined as the presence of hypertriglyceridemia ($\geq$200 mg/dL), high LDL-C ($\geq$160 mg/dL or the use of lipid-lowering medication) or low HDL-C ($<$40 mg/dL), all of which are closely linked to metabolic syndrome [48]. Insulin resistance, a hallmark of metabolic syndrome, contributes to hypertriglyceridemia and plays a central role in dyslipidemia [49]. Since hypertriglyceridemia is strongly associated with abdominal obesity and insulin resistance, reducing abdominal fat through weight loss is crucial for metabolic health [49]. Meta-analyses indicate that regular aerobic and resistance exercise effectively improves dyslipidemia, making it a key strategy for preventing and managing metabolic disorders [50]. HbA1c is widely used as a predictive marker of diabetes and insulin resistance due to its convenience compared to insulin resistance tests and oral glucose tolerance tests. Additionally, HbA1c has been reported to have a strong correlation with cardiovascular disease risk [51, 52]. These findings collectively highlight that metabolic syndrome is not merely a condition of increased body weight or metabolic dysfunction but rather a significant health issue that elevates the risk of cardiovascular and metabolic diseases.

This study also derived threshold values for key metabolic disease indicators predictive of metabolic syndrome. Various cut-off values for biological markers related to the prevention and early diagnosis of metabolic syndrome have been proposed by international organizations and previous studies. However, many of these thresholds have been derived primarily from Western populations, which may not adequately reflect ethnic and lifestyle-specific variations. Therefore, the present study aimed to re-evaluate the applicability of existing cut-off values in Korean middle-aged men (aged 35–64 years) and to establish more precise and population-specific criteria for identifying individuals at increased risk. The results indicate that the thresholds for WC, SBP, DBP, TG, HbA1c and HDL-C were 87.5 cm, 130.5 mmHg, 77.5 mmHg, 156.5 mg/dL, 5.45% and 44.5 mg/dL, respectively. These findings align closely with previously established metabolic syndrome criteria (WC $\geq$90 cm, BP $\geq$130/85 mmHg, TG $\geq$156.5 mg/dL, HbA1c $\geq$6.5%, HDL-C $\leq$40 mg/dL) [28], reaffirming the strong association between metabolic disease factors and metabolic syndrome. Prior studies have shown that regular aerobic and resistance exercise effectively improves dyslipidemia, further supporting its role as a critical intervention for metabolic disease prevention and management [50].

The results of this study indicate that individuals with metabolic syndrome exhibited significantly higher body weight, body fat percentage, and BMI compared to those without the syndrome. In addition, key metabolic indicators such as waist circumference (WC), systolic blood pressure (SBP), diastolic blood pressure (DBP), triglycerides (TG), LDL-cholesterol and HbA1c were markedly elevated in the MetS group, while HDL-cholesterol levels were significantly lower, demonstrating a clear association with metabolic syndrome. Conversely, in terms of health-related fitness, the non-MetS group showed significantly better performance, particularly in sit-ups, push-ups and VO_2max, suggesting that enhancing physical fitness, in addition to managing metabolic risk factors, plays a key role in the prevention and management of metabolic syndrome. The cut-off values for fitness indicators derived from this study, based on data from Korean middle-aged men, offer practical evidence for the development and implementation of exercise-based, personalized health management programs. These values are especially meaningful in that they reflect Korea-specific health determinants, such as lifestyle patterns, genetic predispositions and dietary habits. As such, the findings have potential applications in refining national health screening standards, establishing evidence-based exercise prescriptions, and formulating public health policies for the early identification of high-risk individuals. However, this study was limited to a cross-sectional analysis of middle-aged men aged 35 to 64, and future studies should incorporate broader age ranges and both sexes, as well as consider a variety of lifestyle factors such as diet, alcohol consumption, smoking and physical activity patterns. Furthermore, longitudinal research investigating the long-term impact of maintaining physical fitness on the progression of metabolic syndrome, along with efforts to establish age- and sex-specific fitness thresholds, will contribute to the development of more systematic and effective health management strategies.

5. Conclusions

This study analyzed differences in physical characteristics, health-related fitness, and metabolic disease factors according to the presence of metabolic syndrome in 323 middle-aged men and derived threshold values for health-related fitness and metabolic disease factors to aid in its prevention. The metabolic syndrome group exhibited significantly lower health-related fitness levels and significantly higher metabolic disease indicators compared to the non-MetS group. The threshold values for health-related fitness associated with metabolic syndrome prevention were identified as follows: 29.5 repetitions for sit-ups, 20.5 repetitions for push-ups, relative grip strength of 57.88% (left) and 60.36% (right), 33.5 repetitions for side steps, a vertical jump height of 34.5 cm, and a VO_2max of 39.45 mL/kg/min. The threshold values for metabolic disease indicators were determined as follows: WC of 87.5 cm, SBP of 130.5 mmHg, DBP of 77.5 mmHg, TG of 156.5 mg/dL, HbA1c of 5.45% and HDL-C of 44.5 mg/dL.

In conclusion, to effectively prevent and manage metabolic syndrome in middle-aged men, fitness targets should be set above the threshold values for health-related fitness and below the threshold values for metabolic disease indicators presented in this study. Furthermore, future research should include longitudinal studies involving diverse populations to assess the long-term impact of maintaining fitness levels on metabolic syndrome prevention and improvement.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the corresponding author.

AUTHOR CONTRIBUTIONS

TJK—designed the study and the methodology; drafted the manuscript; were responsible for project administration. TJK and GCH—provided the software, contributed to the resource and data curation, supervised the study. WJC and GCH—contributed to the formal analysis, revised the manuscript. GCH—contributed to data curation. WJC—contributed to data visualization. All authors contributed to the editorial changes in the manuscript. All authors have read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study protocol was approved by the Ethics Committee of the Myongji Hospital, Deoyang-gu, Goyang-si, Gyenggi-do, Republic of Korea (No. 2025-01-009) and conformed to the standards set by the latest revision of the Declaration of Helsinki. Written informed consent was obtained from all study participants.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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