

Impact of lifestyle and its change on the progression and recovery of metabolic syndrome: evidence from the Kailuan Study

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Abstract

Background

As a series of metabolic abnormalities, metabolic syndrome (MetS) is closely linked to lifestyle. When lifestyle changes occur, the status of MetS is also likely to alter. Given the high prevalence of MetS in China, a comprehensive understanding of how lifestyle and its changes affect the prognosis of MetS can aid in better prevention and treatment of MetS in order to reduce the disease burden.

Methods

Based on the Kailuan Study, 58,749 eligible individuals were included. The dynamic patterns were defined by the status of MetS in 2006 and 2010 as follows: MetS free, MetS developed, MetS stable, and MetS recovery. Drinking, smoking, physical activity, and salt intake were included to construct the healthy lifestyle score (HLS). And the difference of HLS between 2008 and 2006 was considered as the changes of lifestyle. Multivariate logistic regression was used to calculate the odds ratio (OR) and 95% confidence interval (CI) to analyze the impact of HLS and changes in HLS on the development and recovery of MetS.

Results

Among individuals without MetS at baseline, for per 1 increment in the HLS, the risk of developing MetS was reduced by 5% (OR = 0.95, 95% CI: 0.93, 0.97). Similarly, for per 1 increment in the HLS change, the risk of developing MetS was decreased by 8% (OR = 0.92, 95% CI: 0.90, 0.95). For those with MetS at baseline, the possibility of recovery from MetS was increased by 8% (OR = 1.08, 95% CI: 1.04, 1.12) with per 1 increment in the HLS. Furthermore, the likelihood of recovering from MetS was increased by 11% (OR = 1.11, 95% CI: 1.06, 1.15).

Conclusion

Adopting a healthy lifestyle or a shift from an unhealthy to a healthy lifestyle can reduce individuals' risk of developing MetS and increase the likelihood of patients with MetS transitioning to a status free of MetS. These findings highlight the importance of healthy lifestyle in the prevention and treatment of MetS.

Introduction

Metabolic syndrome (MetS) is a cluster of metabolic abnormalities that are considered a set of common risk factors for cardiovascular disease and diabetes. According to the definition of the International Diabetes Federation, MetS includes elevated waist circumference (WC), triglycerides (TG), fasting blood

glucose (FBG), blood pressure, and reduced high-density lipoprotein cholesterol (HDL-C). The presence of any three of these could be diagnosed as MetS. Patients with MetS have an increased risk of cardiovascular diseases, type 2 diabetes, some common types of cancer, and all-cause mortality compared to those without MetS ^[1–3]. Moreover, dynamic changes of MetS alter the risks of cardiovascular diseases and all-cause mortality ^[4].

The occurrence of MetS is the result of the interaction between social environment, individual behavior, and pathophysiological factors, among which unhealthy lifestyles are important influencing factors ^[5]. Therefore, it's necessary to clarify the relationship between and MetS. Previous studies have reported that unhealthy lifestyles, such as drinking, smoking, lack of physical activity, and sedentariness increase the risk of MetS ^[6–8], which has been widely accepted. Research results of lifestyle interventions conducted among patients with MetS showed that healthy lifestyle interventions could effectively improve various indicators of patients with MetS ^[9–12], which means that MetS is a changeable and reversible state. It should be emphasized that an individual's lifestyle is not fixed. Merely examining the influence of lifestyle on MetS is not sufficiently comprehensive. At present, there is a paucity of research evidence regarding the impact of lifestyle changes on MetS. Studies that have taken lifestyle changes into account have predominantly concentrated on how these changes affect the risk of developing MetS, without evaluating the effects of lifestyle changes on the recovery of MetS. In China, the prevalence of MetS among adults aged ≥ 40 years is 33.35% ^[13]. Faced with the situation, to achieve effective prevention and management of MetS through healthy lifestyles, there is a pressing need for more comprehensive and detailed epidemiological evidence elucidating the relationship between lifestyles and MetS.

In light of this objective, we utilized data from the Kailuan Study to assess the impact of lifestyle and its changes on the development and recovery of MetS by including smoking status, drinking status, physical activity, and salt intake as four lifestyle risk factors.

Methods

Data source and study population

The data for this study come from the Kailuan Study, which is a prospective community-based cohort study conducted in Tangshan city, Hebei province, China. The detailed study design and procedures have been described previously ^[14, 15]. The Kailuan study began in 2006, enrolling 101,510 individuals (81,110 men and 20,400 women) aged 18 years or older for the baseline survey, with follow-up surveys conducted every two years. The study collected data from participants through face-to-face questionnaires, clinical examinations, and laboratory assessments. The questionnaire used in this study has been previously published and is described in detail elsewhere ^[16]. In this study, data from the baseline survey (2006) and two follow-up surveys (2008 and 2010) was used.

Figure 1 describes the process of selecting the study subjects. In this study, the exclusion criteria were as follows: 1) individuals with missing data of the metabolic syndrome (MetS) status in both the 2006 and 2010 surveys; 2) individuals who had a history of myocardial infarction, stroke, or cancer at baseline; 3) individuals with missing covariates, including age, sex, marital status, education level, income, the number of MetS abnormal components, and the use of anti-hypertensive medication, lipid-lowering medication, and anti-diabetic medication. 58,749 eligible individuals were included in the final analysis. The protocol of this study was approved by the Ethics Committee of the Zhejiang University, School of Medicine and the Kailuan General Hospital. And all individuals agreed to participate in the study and provided written informed consent.

Assessment of lifestyle and covariates

Based on the face-to-face structured questionnaire surveys, information on each individual's lifestyle and covariates were obtained. Smoking status, drinking status, salt intake, and physical activity were the four lifestyle factors considered in this study. Due to the lack of detailed dietary data in the surveys during 2006 to 2010, and referring to previously published studies ^[14, 16–18], we adopted salt intake as a surrogate indicator to measure dietary quality. For smoking status, never smoking is considered healthy, while former smoking, occasional smoking (less than 1 cigarette per day), and daily smoking are considered unhealthy. For drinking status, never drinking is considered healthy, while former drinking, occasional drinking (1 to 3 times per month), and daily drinking are considered unhealthy. Low and moderate salt intake (≤ 10 g per day), occasional and regular (more than 4 times per week with each time lasting less than 20 minutes) physical activity are considered healthy, while high salt intake (> 10 g per day) and inactive physical activity (less than 1 time per week) are considered unhealthy. The definitions of healthy and unhealthy lifestyles were presented in Table 1, with healthy assigned a score of 1 and unhealthy assigned a score of 0. By summing up the scores of the four lifestyle factors, a simple healthy lifestyle score (HLS, ranging from 0 to 4) was constructed. Furthermore, HLS of each individual was assessed at the first follow-up survey in 2008, and the difference from the HLS at the baseline survey in 2006 was calculated (ranging from -4 to 4), to measure the change in healthy lifestyle.

Table 1
The definition of healthy lifestyle

Lifestyle	Healthy	Unhealthy
Smoking status	Never	Former; Occasional; Daily
Drinking status	Never	Former; Occasional; Daily
Salt intake	Low; Moderate	High
Physical activity	Occasional; Regular	Inactive
Smoking status: occasional, less than 1 cigarette per day;		
Drinking status: occasional, 1 to 3 times per month;		
Salt intake: low and moderate, ≤ 10 g per day; high, > 10 g per day;		
Physical activity: inactive, less than 1 time per week; regular, more than 4 times per week with each time lasting less than 20 minutes.		

The covariates included in the study were age, sex, marital status, education level, income, the number of MetS abnormal components, and the use of anti-hypertensive medication, lipid-lowering medication, and anti-diabetic medication. Marital status was categorized as married and unmarried (containing divorced and widowed). Education level was divided into primary school and below, middle school, and high school and above. According to the average monthly household income per capita, it was classified as less than 800 and 800 or more. The use of anti-hypertensive medication, lipid-lowering medication, and anti-diabetic medication were all binary variables (yes or no). In the analysis of changes in healthy lifestyle, further adjustment was made for the baseline HLS.

Definition of MetS and dynamic patterns of MetS

MetS was defined according to the five criteria proposed in the 2009 Joint Statement about MetS. The definition has been widely used currently^[19]. The five criteria are as follows: 1) elevated waist circumference (WC, ≥ 85 cm for men and ≥ 80 cm for women); 2) elevated triglycerides (TG, ≥ 150 mg/dL or 1.7 mmol/L) or using lipid-lowering medication; 3) reduced high-density lipoprotein cholesterol (HDL-C, < 40 mg/dL or 1.0 mmol/L for men and < 50 mg/dL or 1.3 mmol/L for women) or accepting drug treatment for reduced HDL-C; 4) elevated blood pressure (systolic ≥ 130 and/or diastolic ≥ 85 mmHg) or using anti-hypertensive medication; 5) elevated fasting blood glucose (FBG, ≥ 100 mg/dL or 5.6 mmol/L) or using anti-diabetic medication. A diagnosis of MetS could be made if three or more of these criteria were met. According to the MetS status during the surveys in 2006 and 2010, individuals were divided into four groups, which were MetS-free, MetS-developed, MetS-stable, and MetS-recovery, as shown in Fig. 2. For individuals without MetS at baseline, if they were considered to have MetS at the follow-up survey in 2010, they were defined as MetS-developed. Otherwise, they were defined as MetS-free.

Similarly, MetS-stable was defined as the individuals with MetS consistently in 2006 and 2010 and MetS-recovery was those who had MetS in 2006 but were free of MetS in 2010.

Statistical analysis

According to the four dynamic patterns of MetS, baseline characteristics of individuals included in the study were described. Continuous variables were described as the mean $\pm$ standard deviation, while categorical variables were described as the number with percentage. One-way analysis of variance was used for continuous variables and the chi-square test or Fisher's exact test were used for categorical variables to compare the difference of these basic characteristics between groups.

To explore the impact of healthy lifestyles on the development and recovery of MetS, we used multivariate logistic regression models to calculate the adjusted odds ratio (OR) and 95% confidence intervals (95% CI). Based on the HLS, individuals were categorized into four groups with scores of 0 or 1, 2, 3, and 4. Model 1 was adjusted for age, sex, marital status, education level, and income. Model 2 was further adjusted for the number of MetS abnormal components to eliminate the impact of the severity of MetS. Individuals without MetS at baseline were selected to analyze the effect of healthy lifestyles on the development of MetS. When analyzing the effect of healthy lifestyles on the recovery from MetS, individuals who had MetS at baseline were selected.

To investigate the impact of changes in healthy lifestyles on the development and recovery of MetS, the difference in the HLS between 2008 and 2006 was used to measure the changes in healthy lifestyles and constructed multivariate logistic regression models to obtain the OR and 95% CI. And individuals were divided into 5 groups according to their HLS change: 0, 1, 2 ~ 4, -1, and -4~-2. Further adjustment for the HLS at baseline was needed in model 1 and 2. Since some individuals were lost to follow-up and their HLS in 2008 could not be obtained, these individuals were excluded from this analysis. To ensure the representativeness of the sample, the characteristics of the individuals included in this analysis were compared with those excluded.

Several sensitivity analyses were conducted to ensure the robustness of the results, including: 1) stratified analysis by sex and age (< 50 years old, and $\geq$ 50 years old); 2) further adjustment for the use of anti-hypertensive medication, lipid-lowering medication, and anti-diabetic medication in the model; 3) the impact of healthy lifestyles and healthy lifestyle changes on the development and recovery of each MetS component.

All analyses were performed using R software (version 4.0.2). All statistical test were two-sided, and P value < 0.05 was considered to be statistically significant.

Results

Baseline characteristics of the subjects

This study included a total of 58,749 individuals with an average age of 49.0 years, and woman accounted for 22.8%. Table 2 presents the baseline characteristics of the individuals included in the study, grouped by the dynamic patterns of MetS, with 34,293 in the MetS-free group, 9,944 in the MetS-developed group, 5,335 in the MetS-recovery group, and 9,177 in the MetS-stable group. Individuals who consistently had MetS were more likely to be older, women, and to have higher BMI, higher salt intake, hypertension and diabetes. The baseline characteristics of individuals included in the analysis of healthy lifestyle changes and MetS compared to those excluded are presented in **Supplementary Table 1**. There were 48,942 individuals included and 9,807 individuals excluded.

Table 2
Baseline characteristics of individuals by the dynamic patterns of MetS in 2006

Characteristics	MetS free	MetS developed	MetS recovery	MetS stable	P value
Number	34,293	9,944	5,335	9,177	/
Mean age (SD), year	47.6(12.0)	49.1(11.2)	51.9(10.9)	52.3(10.3)	< 0.001
Women, n (%)	7,915(23.1)	2,010(20.2)	1,146(21.5)	2,333(25.4)	< 0.001
Mean BMI (SD), kg/m ²	23.9(3.1)	26.0(3.1)	26.5(3.2)	27.7(3.2)	< 0.001
Education level, n (%)					< 0.001
Primary school and below	2,344(6.8)	746(7.5)	524(9.8)	872(9.5)	
Middle school	24,002(70.0)	7,310(73.5)	3,861(72.4)	6,635(72.3)	
High school and above	7,947(23.2)	1,888(19.0)	950(17.8)	1,670(18.2)	
Married, n (%)	32,800(95.6)	9,587(96.4)	5,185(97.2)	8,869(96.6)	< 0.001
Income less than 800, n (%)	29,446(85.9)	8,628(86.8)	4,610(86.4)	7,859(85.6)	0.070
Mean SBP (SD), mmHg	123.6(18.5)	129.7(19.1)	139.5(18.5)	142(19.1)	< 0.001
Mean DBP (SD), mmHg	80.2(10.7)	83.6(11.0)	88.5(10.9)	89.8(11.3)	< 0.001
Mean WC (SD), cm	83.1(9.2)	87.9(8.8)	91.8(8.4)	94.2(8.4)	< 0.001
Mean FBG (SD), mmol/L	5.06(1.09)	5.35(1.37)	5.94(1.88)	6.51(2.28)	< 0.001
Mean TG (SD), mmol/L	1.27(0.92)	1.72(1.30)	2.44(1.66)	2.81(1.90)	< 0.001
Mean HDL-C (SD), mmol/L	1.58(0.37)	1.55(0.38)	1.51(0.44)	1.47(0.43)	< 0.001
Abbreviation: MetS, metabolic syndrome; SD, standard deviation; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; WC, waist circumference; FBG, fasting blood glucose; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol.					

Characteristics	MetS free	MetS developed	MetS recovery	MetS stable	P value
Mets abnormal components, n (%)					< 0.001
0	9,309(27.1)	824(8.3)	0(0.0)	0(0.0)	
1	14,095(41.1)	3,249(32.7)	0(0.0)	0(0.0)	
2	10,889(31.8)	5,871(59.0)	0(0.0)	0(0.0)	
3	0(0.0)	0(0.0)	4,334(81.2)	5,875(64.0)	
4	0(0.0)	0(0.0)	946(17.7)	2,927(31.9)	
5	0(0.0)	0(0.0)	55(1.0)	375(4.1)	
Hypertension, n (%)	9,706(28.3)	3,930(39.5)	3,640(68.2)	6,610(72.0)	< 0.001
Diabetes, n (%)	979(2.9)	638(6.4)	821(15.4)	2,370(25.8)	< 0.001
Anti-hypertensive drug use, n (%)	1,521(4.4)	861(8.7)	840(15.7)	2,053(22.4)	< 0.001
Lipid-lowering drug use, n (%)	30(0.1)	5(0.1)	173(3.2)	249(2.7)	< 0.001
Anti-diabetic drug use, n (%)	207(0.6)	151(1.5)	185(3.5)	614(6.7)	< 0.001
Abbreviation: MetS, metabolic syndrome; SD, standard deviation; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; WC, waist circumference; FBG, fasting blood glucose; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol.					

Effects of healthy lifestyles and their changes on the developing of MetS

Table 3 shows the effect of healthy lifestyles and their changes on the development of MetS. Daily smoking, drinking, and high salt intake all increased the risk of developing MetS, by 7%, 20%, and 21%, respectively. Compared to individuals who did not engage in physical activity, those who regularly participate in physical activity had a 14% lower risk of developing MetS. As individuals' Healthy Lifestyle Score (HLS) increased, the risk of developing MetS decreased. For each 1 increment in the HLS, the risk of developing MetS decreased by 5% (OR = 0.95, 95% CI: 0.93, 0.97). Using individuals with an HLS of 0 or 1 as the reference group, the ORs of developing MetS for individuals with an HLS of 2, 3, and 4 were 0.90 (0.83, 0.98), 0.80 (0.73, 0.88), and 0.82 (0.75, 0.89), respectively. Regarding those with no change in the HLS (HLS change = 0) as the reference group, the improvement in the HLS (HLS change = 2 ~ 4) reduced the risk of developing MetS by 16% (OR = 0.84, 95% CI: 0.75, 0.94) and the deterioration of the

HLS (HLS change = -4~-2) increased the risk of developing MetS by 21% (OR = 1.21, 95% CI: 1.11, 1.31). Statistically significant results were also observed in the trend tests, with each 1 increment in the HLS change corresponding to an OR of 0.92 (0.90, 0.95) for developing MetS.

Table 3
The effect of healthy lifestyles on the development of MetS.

Lifestyle	MetS free	MetS developed	OR (95% CI)	
			Model 1	Model 2
Single Lifestyle				
Smoking Status				
Never	21,207	6,038	Ref	Ref
Former	1,517	483	1.06(0.95,1.18)	1.07(0.96,1.20)
Occasional	1,296	352	1.00(0.89,1.14)	1.00(0.88,1.13)
Daily	10,273	3,071	1.03(0.98,1.09)	1.07(1.01,1.13)
Drinking Status				
Never	20,506	5,778	Ref	Ref
Former	917	287	1.07(0.93,1.22)	1.08(0.94,1.25)
Occasional	7,320	1,952	1.02(0.96,1.09)	1.06(0.99,1.13)
Daily	5,550	1,927	1.20(1.13,1.28)	1.20(1.12,1.28)
Physical Activity				
Inactive	3,015	910	Ref	Ref
Occasional	26,900	7,798	0.93(0.86,1.01)	0.91(0.84,0.99)
Regular	4,378	1,236	0.86(0.78,0.95)	0.86(0.78,0.96)
Salt Intake				
Low	3,084	808	Ref	Ref
Moderate	27,990	8,056	1.08(0.99,1.17)	1.03(0.94,1.12)
High	3,219	1,080	1.27(1.15,1.41)	1.21(1.09,1.35)
HLS				
0 or 1	3,082	1,037	Ref	Ref
2	8,857	2,659	0.88(0.81, 0.95)	0.90(0.83, 0.98)
3	5,794	1,483	0.76(0.69, 0.83)	0.80(0.73, 0.88)
4	16,560	4,765	0.84(0.77, 0.91)	0.82(0.75, 0.89)
Per 1 increment	/	/	0.95(0.93, 0.97)	0.95(0.93, 0.97)

Lifestyle	MetS free	MetS developed	OR (95% CI)	
			Model 1	Model 2
Single Lifestyle				
HLS change				
0	13,245	3,631	Ref	Ref
1	3,729	1,068	0.94(0.87, 1.03)	0.95(0.87, 1.03)
2 ~ 4	1,905	548	0.85(0.76, 0.95)	0.84(0.75, 0.94)
-1	5,715	1,722	1.11(1.04, 1.19)	1.13(1.06, 1.21)
-2 ~ -4	3,953	1,286	1.25(1.15, 1.35)	1.21(1.11, 1.31)
Per 1 increment	/	/	0.92(0.89, 0.94)	0.92(0.90, 0.95)
Lifestyles contained smoking status, drinking status, salt intake, and physical activity. Never smoking, never drinking, low or moderate salt intake, and occasional or regular physical activity were considered healthy.				
HLS changes were measured by the difference of HLS between 2008 and 2006.				
Abbreviation: MetS, metabolic syndrome; HLS, healthy lifestyle score; OR, odds ratio; CI, confidence interval.				
Model 1: adjust for age, sex, marital status, education level, income.				
Model 2: adjust for Model 1 + the number of MetS abnormal components.				
# Baseline HLS was further adjusted in the Model 1 and Model 2.				

Effects of healthy lifestyles and their changes on the recovery from MetS

Table 4 presents the effect of healthy lifestyles and their changes on the recovery from MetS. Individuals who maintained unhealthy lifestyles had a lower likelihood of recovering from MetS compared to those who kept healthy lifestyles. Specifically, daily smokers had a 15% lower chance of recovery compared to non-smokers, daily drinkers had a 12% lower chance compared to non-drinkers, and those with high salt intake had a 16% lower chance compared to those with low salt intake. Compared to individuals with an HLS of 0 or 1, those with an HLS of 4 had the highest likelihood of recovering from MetS, with an OR of 1.22 (95% CI: 1.07, 1.39). For each 1 increment in the HLS, the likelihood of recovering from MetS increased by 8% (OR = 1.08, 95% CI: 1.04, 1.12). Taking individuals whose HLS remained unchanged (HLS change = 0) as the reference group, it was found that those who experienced an improvement in their HLS (HLS change = 2 ~ 4) had a 35% higher chance of recovering from MetS, with an OR of 1.35 (95% CI: 1.14, 1.60). Individuals whose HLS worsened (HLS change = -4~-2) had a 15% lower chance of

recovering from MetS, with an OR of 0.85 (95% CI: 0.75, 0.97). Additionally, statistically significant results were observed in the trend tests, indicating that for every 1 increase in the HLS change, the possibility of recovering from MetS increased by 11% (OR = 1.11, 95% CI: 1.06, 1.15).

Table 4
The effect of healthy lifestyles on the recovery from MetS.

Lifestyle	MetS stable	MetS recovery	OR (95% CI)	
			Model 1	Model 2
Single Lifestyle				
Smoking Status				
Never	5,664	3,334	Ref	Ref
Former	537	337	0.98(0.85,1.14)	1.02(0.87,1.18)
Occasional	289	174	0.92(0.75,1.12)	0.94(0.77,1.14)
Daily	2,687	1,490	0.84(0.78,0.92)	0.85(0.78,0.92)
Drinking Status				
Never	5,510	3,246	Ref	Ref
Former	292	180	0.95(0.78,1.16)	0.99(0.81,1.21)
Occasional	1,700	933	0.83(0.75,0.92)	0.85(0.76,0.94)
Daily	1,675	976	0.88(0.80,0.97)	0.88(0.80,0.97)
Physical Activity				
Inactive	708	424	Ref	Ref
Occasional	6,972	4,122	1.02(0.90,1.16)	1.01(0.89,1.16)
Regular	1,497	789	0.93(0.80,1.08)	0.97(0.83,1.13)
Salt Intake				
Low	808	473	Ref	Ref
Moderate	7,268	4,308	1.00(0.89,1.13)	0.98(0.87,1.11)
High	1,101	554	0.83(0.71,0.97)	0.84(0.72,0.98)
HLS				
0 or 1	866	481	Ref	Ref
2	2,415	1,354	1.03(0.90, 1.17)	1.02(0.90, 1.17)
3	1,467	861	1.14(0.99, 1.31)	1.13(0.98, 1.30)
4	4,429	2,639	1.24(1.09, 1.41)	1.22(1.07, 1.39)
Per 1 increment	/	/	1.08(1.04, 1.12)	1.08(1.04, 1.12)

Lifestyle	MetS stable	MetS recovery	OR (95% CI)	
			Model 1	Model 2
Single Lifestyle				
HLS change [#]				
0	3,642	2,015	Ref	Ref
1	992	598	1.18(1.05, 1.34)	1.18(1.04, 1.34)
2 ~ 4	534	343	1.33(1.13, 1.57)	1.35(1.14, 1.60)
-1	1,542	808	0.89(0.80, 0.98)	0.89(0.80, 0.99)
-2 ~ -4	1,041	625	0.86(0.76, 0.98)	0.85(0.75, 0.97)
Per 1 increment	/	/	1.11(1.06, 1.15)	1.11(1.06, 1.15)
Lifestyles contained smoking status, drinking status, salt intake, and physical activity. Never smoking, never drinking, low or moderate salt intake, and occasional or regular physical activity were considered healthy.				
HLS changes were measured by the difference of HLS between 2008 and 2006.				
Abbreviation: MetS, metabolic syndrome; HLS, healthy lifestyle score; OR, odds ratio; CI, confidence interval.				
Model 1: adjust for age, sex, marital status, education level, income.				
Model 2: adjust for Model 1 + the number of MetS abnormal components.				
[#] Baseline HLS was further adjusted in the Model 1 and Model 2.				

Sensitivity analyses

When stratified analysis by sex was conducted (**Supplementary Table 2–5**), results observed in men were consistent with the main analysis. In woman, only the results of the trend test in the analysis of the association between healthy lifestyle changes and the development or recovery of MetS were statistically significant, which may be influenced by the smaller sample size of woman in the study. After we conducted the stratified analysis by age with 50 years old as the cutoff (**Supplementary Table 6–9**), we found that the results for individuals younger than 50 years old were consistent with the main analysis. For individuals aged ≥ 50 years old, although there was no statistically significant difference with HLS as a categorical variable in the analysis, there was statistically significant or marginal statistical significance when HLS was analyzed as a continuous variable. The results of additional adjustment for the use of anti-hypertensive drug, lipid-lowering drug, and anti-diabetic drug in the model were also consistent with the main results, as shown in **Supplementary Table 10–13**. Moreover, we

analyzed the impact of healthy lifestyles and healthy lifestyle changes on the development and recovery of each MetS component. These results are presented in the **Supplementary Table 14–33**.

Discussion

In this study, we identified the effect of healthy lifestyles and changes in healthy lifestyles on the progression or recovery of MetS. The healthier the lifestyles, the lower the risk of developing MetS for individuals without MetS at baseline and the higher the likelihood of recovering from MetS for individuals with MetS at baseline. When individuals' healthy lifestyles improved, a lower risk of developing MetS also could be observed, along with a higher possibility of recovery from MetS. On the contrary, when individuals' healthy lifestyles deteriorated, the risk of developing MetS increased and the possibility of recovery decreased.

Previous studies among adults in South Korea ^[6] and Iran ^[20] have also identified a association between a higher number of lifestyle risk factors or a lower HLS and an increased risk of MetS, with a more pronounced effect observed in women. When conducting stratification analysis by sex, we observed that the impact of healthy lifestyle or changes in healthy lifestyles on the progression and recovery of MetS in women was more significant. However, considering that the Kailuan study is a cohort primarily composed of men with a limited number of women, further validation of this finding is necessary. Mahdi et al. ^[20] further explored the effect of HLS on the components of MetS and found that adherence to a healthy lifestyle was associated with a reduced likelihood of high FBG and high TG in Iranian adults. In our results, we not only observed the correlation between healthy lifestyles and high FBG and high TG, but also with high WC, high BP, and low HDL-C. Several surveys ^[13, 21] conducted among the elderly population in China have showed that physical activity, drinking status, and smoking status as independent risk factors for MetS. In our analysis of the impact of single healthy lifestyle on the development and recovery of MetS, our results also confirmed that smoking, drinking, and physical activity could influence the occurrence or recovery of MetS. Meanwhile, Farahnak et al. ^[22] pointed out that reducing salt intake could prevent or delay the progression of MetS later in life.

It is well known that lifestyle is a modifiable risk factor, but few studies have examined how changes in lifestyle affect MetS. Jeffery et al. ^[10] used data from the Heart of New Ulm Project heart health screening program and found that a two-year decrease in optimal lifestyle score was significantly associated with great odds of incident MetS, which was consistent with our results. This finding has important clinical and public health implications, suggesting that we can prevent or retard the incidence of MetS by lifestyle interventions. Several earlier systematic reviews and clinical trials ^[9, 11, 12, 23] have assessed the consequence of lifestyle interventions on MetS, and all studies conveyed decreases in MetS prevalence subsequent to the interventions. Due to the reversible and changeable status of MetS, we also assessed the effect of changes in healthy lifestyles on the recovery from MetS, further illustrating that lifestyle interventions may also make individuals with MetS return to a healthy state. This requires more clinical trials to validate in the future.

There are several strengths in our study. First, by using the large sample cohort of the Kailuan study, we constructed a simple HLS and conducted the analysis of the impact of changes in healthy lifestyles on the development and recovery of MetS, which was rarely investigated in previous research. Second, considering MetS as a reversible and changeable state, we not only examined the effect of healthy lifestyles on the incidence of MetS but also on its recovery, providing more comprehensive evidence for the association between healthy lifestyle and MetS. Third, we conducted several sensitivity analyses to ensure the robustness of the results. This study also has some limitations. Participants in the Kailuan study mainly come from employees of the Kailuan Group and their family members, with the majority of participants being men, which may limit the generalizability of the results. However, previous studies ^[6, 20] have reported a significant association between healthy lifestyles and MetS among women. In addition, due to the lack of detailed information of diet, we used salt intake to assess whether participants' diet were healthy in the construction of the HLS, which may not fully reflect the effect of diet on MetS. Comprehensive evaluations will be needed in the future.

In summary, healthy lifestyles and its changes were associated with the progression and recovery of MetS. The healthier the lifestyle, the lower the risk of MetS progression, and the higher the likelihood of MetS recovery. A deterioration in lifestyles increased the risk of MetS progression and decreased the likelihood of MetS recovery. And an improvement in lifestyles decreased the risk of MetS progression and increased the likelihood of MetS recovery. This suggests the necessity of conducting health education in the general population to advocate for a healthy lifestyle and to implement lifestyle interventions targeting the MetS population.

Abbreviations

MetS

Metabolic syndrome

HLS

Healthy lifestyle score

OR

Odds ratio

CI

Confidence interval

WC

Waist circumference

TG

Triglycerides

FBG

Fasting blood glucose

HDL-C

High-Density Lipoprotein Cholesterol

BMI
Body mass index
BP
Blood pressure

Declarations

Data availability statement

Data are available to researchers on request for purposes of reproducing the results or replicating the procedure by directly contacting the corresponding author.

Ethics approval and consent to participate

The study was reviewed and approved by the Ethics Committee of Zhejiang University, School of Medicine, and Kailuan General Hospital. The participants provided their written informed consent to participate in this study. All procedures involving human participants were conducted in accordance with the ethical standards of the Declaration of Helsinki and its later amendments.

Author contributions

DH designed the protocol of the study. QY and QZ analyzed the data, and wrote the manuscript. WT, YL and SC validated the analysis. SW collected the data. YZ revised the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare no competing interests.

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Consent for publication

Authors give full consent for publication of the current article.

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Figures

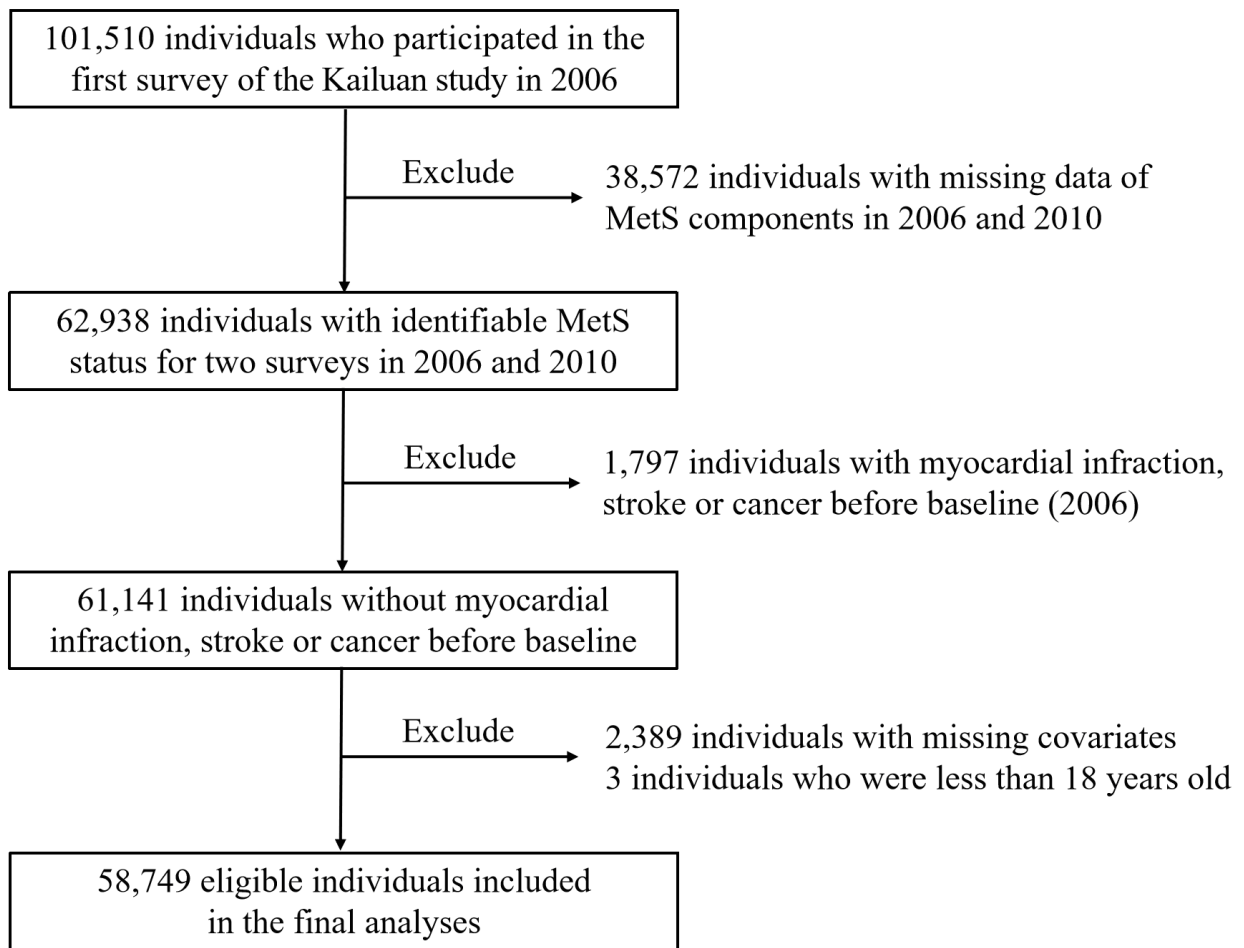


Figure 1

Flowchart of the study population selection

Abbreviation: MetS, metabolic syndrome

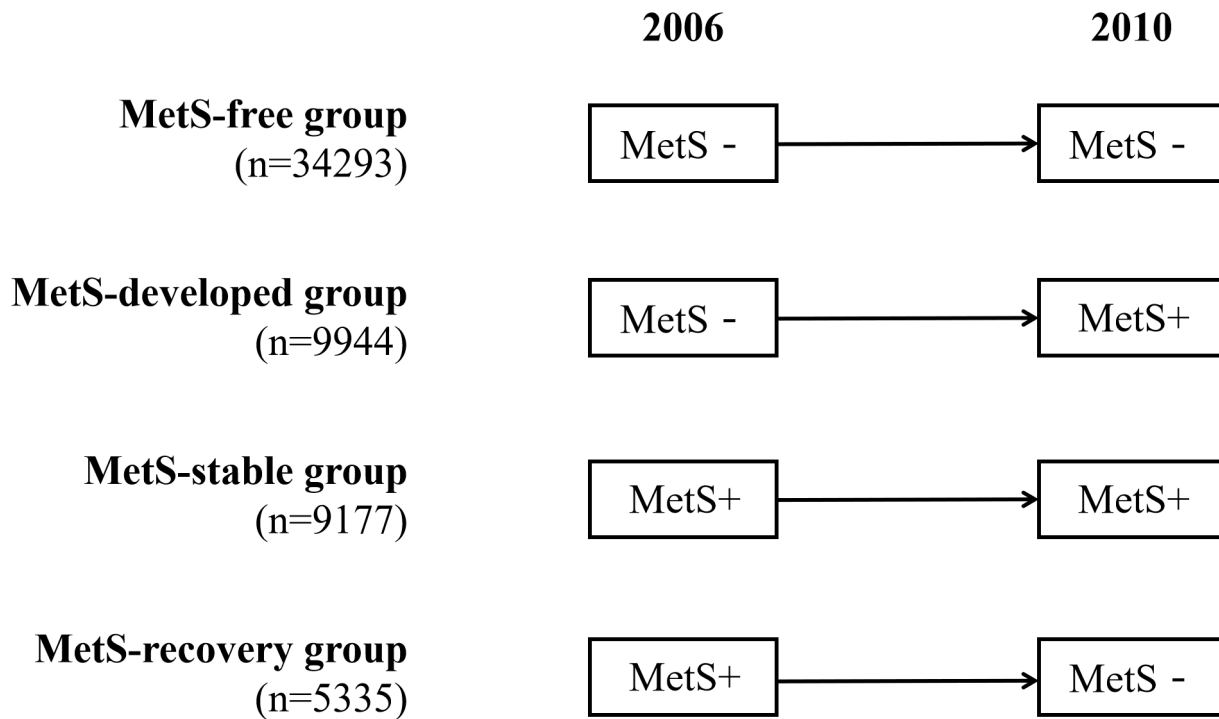


Figure 2

The definition of dynamic patterns of MetS in the study

Abbreviation: MetS, metabolic syndrome

“+” indicates the presence of MetS; “-” indicates no MetS

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