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Sex-specific impact of the COVID-19 outbreak on the incidence of metabolic syndrome: a comparative study of 2018–2019 and 2020–2021

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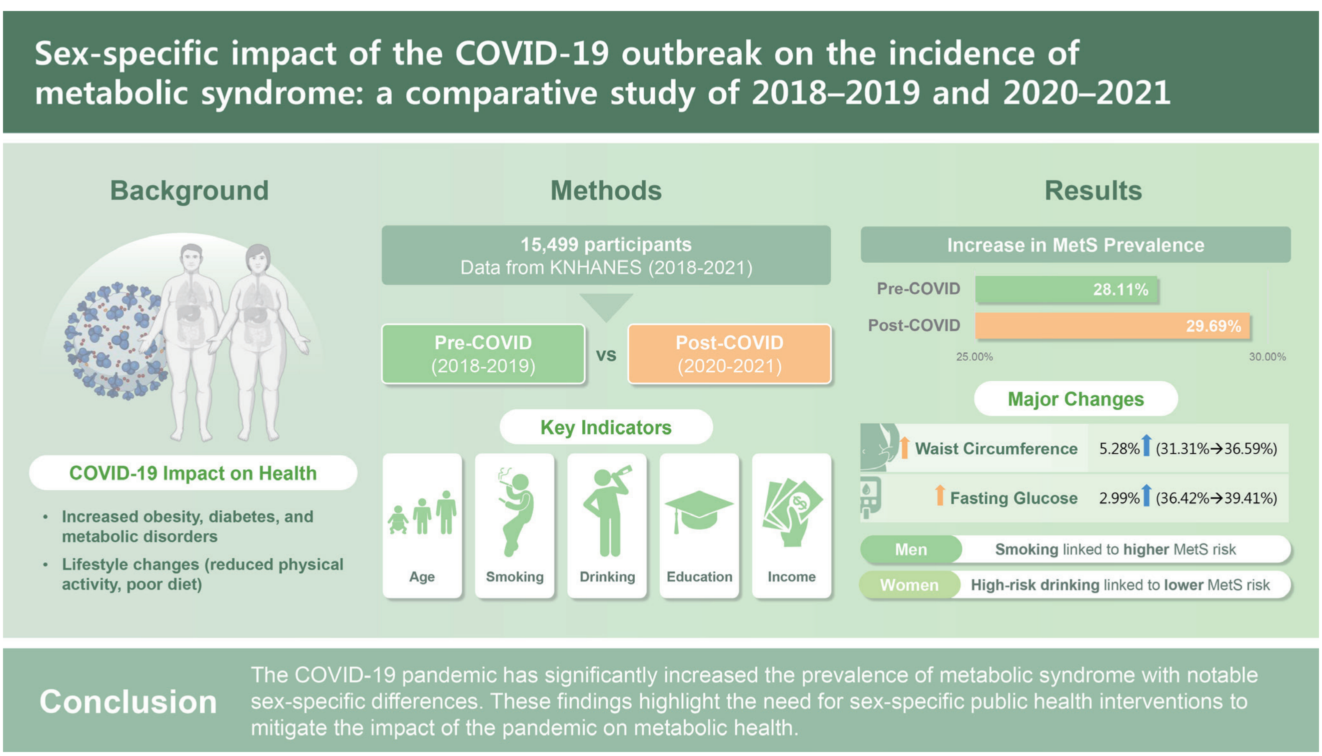

Background/Aims: The coronavirus disease 2019 (COVID-19) pandemic has significantly impacted global health, exacerbated metabolic health issues, and altered lifestyle behaviors. This study examined the sex-specific impact of the COVID-19 outbreak on the incidence of metabolic syndrome using data from the Korea National Health and Nutrition Examination Survey (KNHANES).

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Methods: Data from the KNHANES VII (2018) and VIII (2019–2021), including 15,499 participants, were analyzed. The study population was stratified by sex, and further subdivisions were conducted based on the timeframe relative to the COVID-19 outbreak. Variables such as age, education level, household income, smoking status, and high-risk drinking were analyzed to assess their influence on the prevalence of metabolic syndrome.

Results: The overall prevalence of metabolic syndrome significantly increased from 28.11% before the outbreak to 29.69% after the outbreak. Both males and females reported significant increases in waist circumference and fasting glucose levels. Age and education level differentially influenced the prevalence of metabolic syndrome between the sex. Smoking was significantly associated with increased prevalence in males, whereas high-risk drinking was associated with increased prevalence in males and decreased prevalence in females.

Conclusions: The COVID-19 pandemic has significantly increased the prevalence of metabolic syndrome with notable sex-specific differences. These findings highlight the need for sex-specific public health interventions to mitigate the impact of the pandemic on metabolic health.

Keywords: COVID-19; Metabolic syndrome; Sex factors; Pandemic; Risk factors

INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic has profoundly impacted global health by affecting different aspects of physical and mental well-being. The pandemic has increased morbidity and mortality, disrupted healthcare services, and exacerbated existing health imbalances [1,2]. One significant area of concern is the influence of the pandemic on metabolic health, particularly the prevalence of metabolic syndrome [3]. Metabolic syndrome is a cluster of conditions that increases the risk of cardiovascular diseases and type 2 diabetes, including abdominal obesity, hypertriglyceridemia, low high-density lipoprotein (HDL) cholesterol, hypertension, and high fasting glucose [4] Recent studies have reported worsening metabolic profiles during the pandemic [5,6]. The pandemic's influence on lifestyle behaviors, such as reduced physical activity, altered dietary habits, and increased stress levels, has likely exacerbated the risk factors associated with metabolic syndrome [7,8].

Sex-specific differences in the prevalence and impact of metabolic syndrome components have been well-documented [9,10]. Males typically exhibit higher rates of abdominal obesity and hypertension, whereas females often have lower HDL cholesterol levels. Furthermore, two recent studies in Asian patients have shown that sex may have a differential impact on the prevalence of metabolic syndrome, depending on socioeconomic status [11] and patterns of daily activity, and not just physical activity [12]. These differences emphasize the necessity of understanding how the COVID-19 pandemic may differentially affect these patterns across sex.

This study explored the sex-specific impact of the COVID-19 outbreak on the incidence of metabolic syndrome by comparing its prevalence and associated risk factors before and after the pandemic using data from the Korea National Health and Nutrition Examination Survey (KNHANES).

METHODS

Study population

This study used data from KNHANES conducted between 2018 (KNHANES VII) and 2019–2021 (KNHANES VIII), encompassing 30,551 participants. Since 1998, the Division of Chronic Disease Surveillance of the Korean Centers for Disease Control and Prevention has performed the KNHANES annually. This cross-sectional and nationally representative survey comprises a health interview and nutrition and health examinations to assess the health and nutritional status of the Korean population. Participants who met the inclusion criteria were selected from the dataset, resulting in a final sample size of 15,499 individuals (Fig. 1). The selection criteria excluded individuals under 19 years of age and those with incomplete data or missing information critical for analyzing metabolic syndrome components. The study population was stratified by sex and comprised 7,881 males and 7,618 females. These groups were further subdivided based on the timeframe of the COVID-19 outbreak. Given

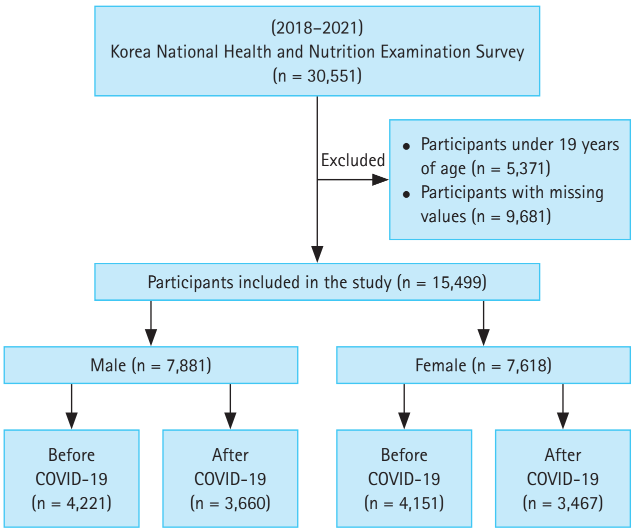

Figure 1. Study population.

that the KNHANES categorizes data by fiscal year and that the first case of COVID-19 in South Korea was confirmed in January 20, 2020, the 2018–2019 data were categorized as pre-COVID, with corresponding participants in the pre-COVID group, and the 2020–2021 survey data were categorized as post-COVID, with corresponding participants in the post-COVID group. Among males, there were 4,221 participants in the pre-COVID-19 group and 3,660 in the post-COVID-19 group. Similarly, 4,151 females were present in the pre-COVID-19 group and 3,467 females in the post-COVID-19 group.

In this study, we utilized de-identified data from the KNHANES. The study protocol was reviewed and approved by the Institutional Review Board (IRB) of Yonsei University (IRB No. CR323362). The requirement for informed consent was waived because participant consent was obtained from the KNHANES. The dataset is in the public domain and does not contain any individually identifiable information.

Data collection

Data collection involved a comprehensive set of variables relevant to metabolic syndrome and its components. The variables collected included sex, age, education level (below university level and university level or higher), and household income (divided into two quartiles, first and second quartiles and third and fourth quartiles, with third and fourth quartiles representing higher income levels). Smoking status was classified as never smoking or not smoking, and non-never smokers were defined as individuals who had smoked a minimum of five packs of cigarettes over their lifetime. High-risk drinking was defined as consuming more than seven glasses of alcohol on a single occasion for males and more than five glasses for females on two or more occasions per week. Physical activity was indicated by whether the participant engaged in regular exercise, characterized as physical activity for at least 30 min per session, five or more times per week. Waist circumference was measured at the narrowest point between the upper iliac crest and lowest rib after normal expiration. Systolic and diastolic blood pressure (BP) were recorded in mmHg. Laboratory samples, including fasting glucose, triglycerides, and HDL cholesterol levels measured in mg/dL, were obtained after a 12-h fast. These variables were meticulously recorded for each participant to ensure a thorough analysis of the incidence and prevalence of metabolic syndrome before and after the COVID-19 outbreak. Data collection methods adhered to standardized procedures to maintain consistency and reliability across the study period, enabling the investigation of potential changes in metabolic health and identifying risk factors associated with the COVID-19 pandemic.

Definition of metabolic syndrome

Metabolic syndrome was defined according to harmonized criteria established by multiple international organizations, including the International Diabetes Federation; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. These criteria are modifications of the National Cholesterol Education Program Adult Treatment Panel III guidelines. Metabolic syndrome was diagnosed when an individual presented with three or more of the following components [13]: 1. Abdominal obesity was defined as a waist circumference of ≥ 90 cm for males or ≥ 85 cm for females, according to the Korean-specific cutoffs set by the Korean Society of Obesity [14], 2. hypertriglyceridemia was identified by a serum triglyceride level of ≥ 150 mg/dL, 3. low HDL cholesterol levels were defined as a serum HDL cholesterol concentration < 40 mg/dL for males and < 50 mg/dL for females, 4. high BP was characterized by systolic BP of ≥ 130 mmHg or diastolic BP of ≥ 85 mmHg or the use of antihypertensive medication, 5. high fasting glucose was marked by a fasting serum glucose level of ≥ 100 mg/dL or the current use of antidiabetic medication, including oral hypoglycemic agents or insulin.

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Statistical analysis

Descriptive statistics were calculated for all the participants to outline their baseline characteristics. For categorical variables, comparisons between groups were performed using the chi-square test, whereas continuous variables were compared using the t-test. To compare the prevalence of metabolic syndrome and its components before and after the COVID-19 outbreak, the chi-square test was used to analyze categorical variables, and *p* values were calculated to determine statistical significance. Non-parametric tests were used for continuous variables that did not follow a normal distribution. The Mann–Whitney U test was used to compare two independent groups. Logistic regression analysis was used to evaluate the association between the COVID-19 outbreak and the prevalence of metabolic syndrome and its components by calculating odds ratios (ORs) and 95% confidence intervals (CIs). The OR represents the odds of developing metabolic syndrome after exposure to the COVID-19 outbreak compared with the odds of developing metabolic syndrome without the COVID-19 outbreak. Further stratified analysis was performed by age group (19–29, 30–39, 40–49, 50–59, 60–69, and 70 yr and older) to examine the impact across different age demographics. These analyses were additionally stratified by sex to explore sex-specific effects. Logistic regression analyses were also performed to assess the odds of developing metabolic syndrome based on age, education level, household income, smoking status, high-risk drinking, and physical activity before and after the COVID-19 outbreak. Separate analyses were conducted for males and females to identify potential differences between sex. The results are represented as ORs with 95% CIs to provide a comprehensive understanding of the risk factors associated with metabolic syndrome in the context of the COVID-19 pandemic.

Subgroup analyses were conducted to evaluate whether the interaction between the COVID-19 outbreak and metabolic syndrome prevalence differed by sex across different subgroups, including age (< 65 yr vs. ≥ 65 yr), education level, household income, smoking status, high-risk drinking, and physical activity. In this analysis, the OR represents the risk of developing metabolic syndrome in females compared to males. Interaction *p* values were calculated to determine whether the impact of the COVID-19 outbreak on metabolic syndrome differed significantly between males and females in each subgroup. A significant interaction *p* value indicated that the relationship between COVID-19 and the prevalence of metabolic syndrome differed between males and females within the subgroups analyzed.

All statistical analyses were conducted using SAS software (version 9.4; SAS Institute Inc., Cary, NC, USA), and statistical significance was set at $p < 0.05$. These rigorous statistical methods ensured the robustness and reliability of the findings.

RESULTS

Baseline characteristics

The baseline characteristics of the study population were summarized and compared before and after the COVID-19 outbreak (Table 1). The study population comprised 15,499 individuals, with 8,372 participants before COVID-19 and 7,127 participants after the COVID-19 outbreak. Significant differences between the pre- and post-COVID-19 groups were observed in household income, waist circumference, diastolic BP, and fasting glucose levels. When analyzed separately by sex, both males and females showed significant differences in household income and waist circumference. In terms of household income level, the difference before and after COVID-19 did not reflect an actual change in the amount of household income, as the distribution of the surveyed participants changed slightly between KNHANES VII (2018) and VIII (2019–2021). For males, waist circumference increased significantly from 87.35 ± 9.17 cm to 88.64 ± 9.42 cm ($p < 0.001$), and systolic BP showed a significant increase post-COVID-19 ($p = 0.001$). For females, waist circumference increased from 78.80 ± 9.98 cm to 79.86 ± 10.27 cm ($p < 0.001$), and diastolic BP significantly decreased ($p < 0.001$), with mean values dropping from 74.33 ± 9.54 mmHg to 72.86 ± 9.33 mmHg. In addition, fasting glucose levels in females increased significantly in post-COVID-19, from 97.01 ± 18.06 mg/dL to 98.50 ± 20.39 mg/dL ($p = 0.001$).

Prevalence of metabolic syndrome before and after the COVID-19 outbreak

The prevalence of metabolic syndrome and its components before and after the COVID-19 outbreak are provided in Table 2. In the entire study population, the prevalence of metabolic syndrome increased significantly from 28.11% before COVID-19 to 29.69% after COVID-19 ($p = 0.030$). Among the components of metabolic syndrome, the percentage of

Table 1. Baseline characteristics of the study population

Variable	All population			Male			Female		
	Before COVID-19 (n = 8,372)	After COVID-19 (n = 7,127)	*p* value	Before COVID-19 (n = 4,221)	After COVID-19 (n = 3,660)	*p* value	Before COVID-19 (n = 4,151)	After COVID-19 (n = 3,467)	*p* value
Sex			0.245						
Male	4,221 (50.42)	3,660 (51.35)							
Female	4,151 (49.58)	3,467 (48.65)							
Age (yr)	48.08 ± 16.00	48.22 ± 16.30	0.580	48.79 ± 16.50	49.31 ± 16.66	0.168	47.36 ± 15.45	47.08 ± 15.84	0.441
Education level			0.560			0.420			0.104
< University	4,787 (57.18)	4,042 (56.71)		2,348 (55.63)	2,069 (56.53)		2,439 (58.76)	1,973 (56.91)	
≥ University	3,585 (42.82)	3,085 (43.29)		1,873 (44.37)	1,591 (43.47)		1,712 (41.24)	1,494 (43.09)	
Household income			< 0.001			0.006			< 0.001
1st & 2nd quartiles	3,186 (38.06)	2,430 (34.10)		1,569 (37.17)	1,251 (34.18)		1,617 (38.95)	1,179 (34.01)	
3rd & 4th quartiles	5,186 (61.94)	4,697 (65.90)		2,652 (62.83)	2,409 (65.82)		2,534 (61.05)	2,288 (65.99)	
Smoking			0.958			0.162			0.885
Never	4,465 (53.33)	3,804 (53.37)		946 (22.41)	869 (23.74)		3,519 (84.77)	2,935 (84.66)	
Not never	3,907 (46.67)	3,323 (46.63)		3,275 (77.59)	2,791 (76.26)		632 (15.23)	532 (15.34)	
High-risk drinking			0.830			0.919			0.365
No	4,373 (52.23)	3,735 (52.41)		1,647 (39.02)	1,424 (38.91)		2,726 (65.67)	2,311 (66.66)	
Yes	3,999 (47.77)	3,392 (47.59)		2,574 (60.98)	2,236 (61.09)		1,425 (34.33)	1,156 (33.34)	
Physical activity			0.784			0.428			0.213
No	3,286 (39.25)	2,782 (39.03)		1,679 (39.78)	1,488 (40.66)		1,607 (38.71)	1,294 (37.32)	
Yes	5,086 (60.75)	4,345 (60.97)		2,542 (60.22)	2,172 (59.34)		2,544 (61.29)	2,173 (62.68)	
Waist circumference (cm)	83.11 ± 10.49	84.37 ± 10.78	< 0.001	87.35 ± 9.17	88.64 ± 9.42	< 0.001	78.80 ± 9.98	79.86 ± 10.27	< 0.001
Triglycerides (mg/dL)	135.07 ± 110.75	132.49 ± 114.41	0.157	159.33 ± 128.20	156.58 ± 140.36	0.367	110.39 ± 82.58	107.06 ± 69.68	0.056
HDL cholesterol (mg/dL)	52.66 ± 12.92	52.57 ± 13.11	0.671	48.55 ± 11.56	48.31 ± 11.42	0.344	56.84 ± 12.88	57.07 ± 13.27	0.434
Systolic BP (mmHg)	117.88 ± 15.85	118.29 ± 15.67	0.103	120.67 ± 14.55	121.85 ± 14.44	0.001	115.04 ± 16.59	114.54 ± 16.05	0.185
Diastolic BP (mmHg)	76.20 ± 9.98	75.43 ± 9.99	< 0.001	78.05 ± 10.06	77.85 ± 9.98	0.388	74.33 ± 9.54	72.86 ± 9.33	< 0.001
Fasting glucose (mg/dL)	100.47 ± 22.12	101.69 ± 22.88	0.001	103.88 ± 25.02	104.71 ± 24.64	0.141	97.01 ± 18.06	98.50 ± 20.39	0.001

Values are presented as number (%) or mean ± standard deviation.
HDL, high-density lipoprotein; BP, blood pressure.
p values were derived using the chi-square test or independent t-test.

Table 2. Comparison of metabolic syndrome components before and after the COVID-19 outbreak

	All population			Male			Female		
	Before COVID-19 (n = 8,372)	After COVID-19 (n = 7,127)	*p* value	Before COVID-19 (n = 4,221)	After COVID-19 (n = 3,660)	*p* value	Before COVID-19 (n = 4,151)	After COVID-19 (n = 3,467)	*p* value
Metabolic syndrome	2,353 (28.11)	2,116 (29.69)	0.030	1,446 (34.73)	1,341 (36.64)	0.078	887 (21.37)	775 (22.35)	0.300
Metabolic syndrome components									
Elevated waist circumference	2,621 (31.31)	2,608 (36.59)	< 0.001	1,580 (37.43)	1,575 (43.03)	< 0.001	1,041 (25.08)	1,033 (29.80)	< 0.001
Hypertriglyceridemia	2,458 (29.36)	2,006 (28.15)	0.096	1,657 (39.26)	1,378 (37.65)	0.144	801 (19.30)	628 (18.11)	0.188
Low HDL cholesterol	2,147 (25.65)	1,859 (26.08)	0.534	917 (21.72)	818 (22.35)	0.504	1,230 (29.63)	1,041 (30.03)	0.708
High blood pressure	3,245 (38.76)	2,706 (37.97)	0.312	1,979 (46.88)	1,706 (46.61)	0.809	1,266 (30.50)	1,000 (28.84)	0.116
High fasting glucose	3,049 (36.42)	2,809 (39.41)	0.001	1,863 (44.14)	1,731 (47.30)	0.005	1,186 (28.57)	1,078 (31.09)	0.017

Values are presented as number (%).
HDL, high-density lipoprotein cholesterol.

individuals with elevated waist circumference increased significantly from 31.31% to 36.59% ($p < 0.001$). In addition, the prevalence of high fasting glucose levels increased significantly from 36.42% to 39.41% ($p = 0.001$). Other components, such as hypertriglyceridemia, low HDL cholesterol, and high BP, did not show significant changes. In males, the prevalence of metabolic syndrome increased from 34.73% before COVID-19 to 36.64% after COVID-19, although this change was not statistically significant ($p = 0.078$). However, the percentage of males with elevated waist circumference increased significantly from 37.43% to 43.03% ($p < 0.001$) and the prevalence of high fasting glucose increased significantly from 44.14% to 47.30% ($p = 0.005$). In females, the prevalence of metabolic syndrome increased from 21.37% before COVID-19 to 22.35% after COVID-19; however, this change was not statistically significant ($p = 0.300$). However, the percentage of females with elevated waist circumference increased significantly from 25.08% to 29.80% ($p < 0.001$). Furthermore, the prevalence of high fasting glucose levels increased significantly from 28.57% to 31.09% ($p = 0.017$). Other components, including hypertriglyceridemia, low HDL cholesterol, and high BP, did not show significant changes. These findings indicate that the prevalence of metabolic syndrome and specific components, such as elevated waist circumference and high fasting glucose levels, increased significantly after the COVID-19 outbreak.

Sex-specific impact of COVID-19 outbreak on metabolic syndrome

Table 3 shows that the adjusted OR for developing metabolic syndrome after the COVID-19 outbreak was 1.09 (95% CI 1.02–1.18). Among the components of metabolic syndrome, elevated waist circumference and fasting glucose levels are significantly associated with COVID-19. An OR of 1.29 (95% CI 1.20–1.38) for elevated waist circumference means that individuals are 29% more likely to have an elevated waist circumference after the COVID-19 outbreak compared to before. Similarly, an OR of 1.15 (95% CI 1.08–1.23) for high fasting glucose indicates a 15% increased probability post-outbreak. Other components, such as hypertriglyceridemia, low HDL cholesterol, and high BP, did not show significant associations. In males, the development of metabolic syndrome was not significantly associated with the COVID-19 outbreak. However, substantial increases were observed in specific components, including elevated waist circumference and fasting glucose levels. In females, the development of metabolic syndrome was significantly associated with the COVID-19 outbreak. Elevated waist circumference had an OR of 1.36, and high fasting glucose had an OR of 1.18, both of which showed significant increases. The COVID-19 outbreak has significantly affected the prevalence of metabolic syndrome, primarily through increases in waist circumference and fasting glucose levels, with varying degrees of significance between males and females.

According to the age group (Table 4), the adjusted OR for developing metabolic syndrome was 1.41 (95% CI 1.04–1.90) in the 19–29 age group, indicating a significant 41% increase after the COVID-19 outbreak compared to before. Elevated waist circumference showed the most pronounced increase in the younger age groups, with an OR of 1.53 (95% CI 1.23–1.90) for the 19–29 age group. For high fasting glucose, the association with the COVID-19 outbreak increased with age, showing ORs of 1.18 (95% CI 1.02–1.37) in the 50–59 age group and 1.25 (95% CI 1.02–1.52) in the 70 and older age group. These OR values indicated an 18% and 25% higher likelihood of high fasting glucose levels in the respective age groups post-COVID-19. In males, significant increases in elevated waist circumference were also observed in younger age groups. For high fasting glucose, the OR was significant in the 30–39 age group, the 50–59 age group, and the 70 and older age group. Similarly, in females, elevated waist circumference showed a significant increase in younger age groups. The OR for high fasting glucose levels was significantly correlated with COVID-19 in the 60–69 age group. Overall, the OR values in these analyses showed varying effects of the COVID-19 outbreak on different age groups, highlighting significant increases in metabolic syndrome and its components, especially elevated waist circumference and high fasting glucose, across different demographics.

Sex differences in factors influencing metabolic syndrome before and after COVID-19

Factors influencing the association between metabolic syndrome before and after the COVID-19 outbreak are shown in Table 5, with notable differences and similarities between males and females. Higher age was consistently associated with increased metabolic syndrome in both sex. In contrast, higher education level and household income were protective factors, reducing the ORs for metabolic syndrome in both males and females. Although non-smoking was significantly associated with increased metabolic syndrome in males, it had no significant impact on females. High-risk drinking was associated with increased and decreased metabolic syndrome in males and females, respectively. Regular physical activity was associated with lower metabolic syndrome in both males and females, highlighting its importance as a protective factor across sex. These findings emphasize the complicated interplay between demographic and lifestyle factors that influence metabolic syndrome during the pandemic.

Supplementary Table 1 provides a subgroup analysis evaluating the interaction effects of different factors on the prevalence of metabolic syndrome between males and females stratified by the COVID-19 outbreak. Significant inter-

Table 3. Logistic regression of metabolic syndrome according to the COVID-19 outbreak

	All population	Male	Female
Metabolic syndrome	1.09 (1.02–1.18)*	1.09 (0.99–1.19)	1.13 (1.00–1.27)*
Metabolic syndrome components			
Elevated waist circumference	1.29 (1.20–1.38)*	1.26 (1.15–1.38)*	1.36 (1.22–1.52)*
Hypertriglyceridemia	0.94 (0.88–1.02)	0.95 (0.86–1.04)	0.95 (0.84–1.07)
Low HDL cholesterol	1.04 (0.97–1.12)	1.05 (0.94–1.17)	1.04 (0.94–1.15)
High blood pressure	0.96 (0.90–1.03)	0.98 (0.89–1.08)	0.95 (0.85–1.06)
High fasting glucose	1.15 (1.08–1.23)*	1.14 (1.04–1.25)*	1.18 (1.06–1.31)*

Values are presented as odds ratio (95% confidence interval).
HDL, high-density lipoprotein.
Logistic regression analysis was adjusted for age, sex, education level, household income, smoking status, high-risk drinking, and physical activity.
*Indicates statistical significance.

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Table 4. Logistic regression for metabolic syndrome according to the COVID-19 outbreak and age group

Variable	19–29 yr	30–39 yr	40–49 yr	50–59 yr	60–69 yr	≥ 70 yr
All population						
Metabolic syndrome	1.41 (1.04–1.90)*	1.19 (0.96–1.47)	1.06 (0.89–1.25)	1.12 (0.96–1.31)	1.04 (0.89–1.22)	1.06 (0.87–1.28)
Metabolic syndrome components						
Elevated waist circumference	1.53 (1.23–1.90)*	1.41 (1.18–1.69)*	1.37 (1.17–1.61)*	1.28 (1.10–1.49)*	1.14 (0.97–1.33)	1.32 (1.09–1.60)*
Hypertriglyceridemia	1.16 (0.92–1.45)	0.98 (0.81–1.18)	1.01 (0.86–1.19)	0.93 (0.80–1.09)	0.87 (0.73–1.02)	0.79 (0.63–0.99)
Low HDL cholesterol	1.18 (0.96–1.46)	1.12 (0.92–1.35)	0.97 (0.82–1.14)	1.03 (0.88–1.21)	1.02 (0.85–1.21)	1.02 (0.83–1.26)
High blood pressure	0.93 (0.71–1.20)	0.90 (0.72–1.11)	0.94 (0.80–1.10)	1.03 (0.89–1.20)	0.98 (0.83–1.15)	0.88 (0.70–1.10)
High fasting glucose	1.12 (0.86–1.46)	1.27 (1.05–1.53)*	1.07 (0.92–1.24)	1.18 (1.02–1.37)*	1.18 (1.00–1.38)*	1.25 (1.02–1.52)*
Male						
Metabolic syndrome	1.42 (0.99–2.03)	1.10 (0.85–1.42)	1.03 (0.84–1.28)	1.12 (0.91–1.39)	1.01 (0.82–1.25)	1.11 (0.87–1.43)
Metabolic syndrome components						
Elevated waist circumference	1.50 (1.16–1.94)*	1.44 (1.14–1.81)*	1.32 (1.07–1.62)*	1.21 (0.98–1.50)	1.16 (0.94–1.43)	1.15 (0.90–1.48)
Hypertriglyceridemia	1.17 (0.89–1.54)	1.02 (0.81–1.29)	0.96 (0.78–1.18)	0.89 (0.72–1.10)	0.92 (0.74–1.14)	0.81 (0.61–1.07)
Low HDL cholesterol	1.15 (0.84–1.58)	1.13 (0.86–1.50)	0.88 (0.69–1.12)	1.05 (0.82–1.34)	1.11 (0.86–1.42)	1.11 (0.83–1.48)
High blood pressure	0.99 (0.73–1.33)	0.88 (0.68–1.13)	0.95 (0.77–1.17)	1.15 (0.93–1.43)	0.92 (0.74–1.15)	0.89 (0.67–1.18)
High fasting glucose	1.06 (0.75–1.49)	1.32 (1.03–1.68)*	0.99 (0.80–1.22)	1.23 (1.00–1.53)*	1.06 (0.85–1.32)	1.31 (1.01–1.69)*
Female						
Metabolic syndrome	1.37 (0.79–2.39)	1.37 (0.95–1.99)	1.10 (0.83–1.45)	1.14 (0.91–1.44)	1.10 (0.86–1.41)	0.99 (0.72–1.34)
Metabolic syndrome components						
Elevated waist circumference	1.59 (1.06–2.38)*	1.42 (1.07–1.88)*	1.47 (1.15–1.87)*	1.40 (1.12–1.75)*	1.15 (0.90–1.46)	1.64 (1.19–2.25)*
Hypertriglyceridemia	1.09 (0.72–1.64)	0.91 (0.66–1.24)	1.10 (0.84–1.43)	0.99 (0.78–1.26)	0.79 (0.60–1.03)	0.76 (0.53–1.10)
Low HDL cholesterol	1.19 (0.89–1.57)	1.10 (0.85–1.42)	1.05 (0.84–1.32)	1.03 (0.83–1.28)	0.93 (0.72–1.18)	0.93 (0.68–1.27)
High blood pressure	0.75 (0.44–1.28)	0.90 (0.60–1.35)	0.93 (0.73–1.19)	0.93 (0.76–1.15)	1.06 (0.83–1.35)	0.83 (0.58–1.20)
High fasting glucose	1.23 (0.80–1.89)	1.20 (0.89–1.62)	1.17 (0.93–1.47)	1.13 (0.92–1.39)	1.31 (1.03–1.66)*	1.17 (0.86–1.60)*

Values are presented as odds ratio (95% confidence interval).
HDL, high-density lipoprotein.
Logistic regression analysis was adjusted for age, sex, education level, household income, smoking status, high-risk drinking, and physical activity.
*Indicates statistical significance.

Table 5. Logistic regression analysis of metabolic syndrome

Variable	Male		Female	
	Before COVID-19	After COVID-19	Before COVID-19	After COVID-19
Age	1.03 (1.03–1.04)*	1.03 (1.03–1.04)*	1.07 (1.06–1.08)*	1.06 (1.06–1.07)*
Education level				
< University	Ref.	Ref.	Ref.	Ref.
≥ University	0.73 (0.64–0.83)*	0.72 (0.63–0.83)*	0.27 (0.22–0.32)*	0.36 (0.30–0.43)*
Household income				
1st & 2nd quartiles	Ref.	Ref.	Ref.	Ref.
3rd & 4th quartiles	0.94 (0.82–1.07)	0.80 (0.70–0.92)*	0.43 (0.37–0.50)*	0.42 (0.36–0.49)*
Smoking				
Never	Ref.	Ref.	Ref.	Ref.
Not never	1.54 (1.31–1.80)*	1.72 (1.46–2.03)*	0.86 (0.70–1.07)	0.96 (0.77–1.20)
High-risk drinking				
No	Ref.	Ref.	Ref.	Ref.
Yes	1.55 (1.36–1.77)*	1.42 (1.23–1.63)*	0.74 (0.63–0.87)*	0.69 (0.58–0.83)*
Physical activity				
No	Ref.	Ref.	Ref.	Ref.
Yes	0.85 (0.74–0.96)*	0.82 (0.72–0.95)*	0.82 (0.71–0.96)*	0.77 (0.66–0.91)*

Values are presented as odds ratio (95% confidence interval).
*Indicates statistical significance.

actions were observed for age, education level, household income, smoking status, and high-risk drinking, suggesting that these factors differentially influenced the risk of metabolic syndrome between sex before and after the COVID-19 outbreak. Younger females (< 65 yr) had a significantly lower prevalence of metabolic syndrome than males, whereas older females (≥ 65 yr) had a higher prevalence than men before the COVID-19 pandemic. This pattern has persisted even after the COVID-19 outbreak. Females with university education or higher had a significantly lower prevalence of metabolic syndrome than similarly educated males, a difference that was more pronounced than in those with less education, and this trend persisted after COVID-19. Higher household income, no smoking, and high-risk drinking showed patterns similar to those observed for education level, with significant differences between males and females persisting before and after COVID-19.

Supplementary Table 2 provides baseline patient characteristics according to age group. As the above analysis showed a pattern of elevated waist circumference in younger age groups, especially in males, and higher fasting blood glucose levels in older participants, we analyzed the differences in factors according to age before and after COVID-19. According to this table, among all participants, regular physical activity was performed by 61.45% of participants aged 19–49 years and 60.17% of participants aged ≥ 50 years with no statistical difference. However, when comparing pre- and post-COVID-19 periods, as seen in Supplementary Table 3, we found that before the COVID-19 pandemic, the proportion of participants performing regular physical activity was statistically lower in those aged ≥ 50 years than in those aged 19–49 years (59.49% vs. 61.83%, $p = 0.029$), but after COVID-19, this statistical difference disappeared (60.94% vs. 60.99%, $p = 0.965$). Although not significantly different, this trend was more pronounced in males, where regular physical activity tended to be lower in males aged ≥ 50 years than in those aged 19–49 years before COVID-19 (58.89% vs. 61.46%, $p = 0.088$); however, this trend was not observed post-COVID-19.

DISCUSSION

Investigation of the sex-specific impact of the COVID-19

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outbreak on metabolic syndrome revealed several important findings. The overall prevalence of metabolic syndrome increased significantly from 28.11% before the outbreak to 29.69% after the outbreak, with significant increases in waist circumference and fasting glucose levels in both males and females. Sex-specific analyses highlighted that males experienced significant increases in waist circumference and fasting glucose levels, while females showed notable increases in these components as well. In addition, factors such as age, education level, household income, smoking status, and high-risk drinking differentially influenced the prevalence of metabolic syndrome in males and females. Younger females had a lower prevalence of metabolic syndrome than males, whereas older females had a higher prevalence. Higher education levels and household income were more protective against metabolic syndrome in females than in males. Smoking was significantly associated with an increased prevalence of metabolic syndrome in males; however, it exerted no significant impact on females. High-risk drinking was associated with an increased prevalence of metabolic syndrome in males, whereas it was associated with a decreased prevalence in females. These findings emphasize the necessity of sex-specific strategies to address metabolic health issues, particularly in global health crises such as the COVID-19 pandemic.

A significant association between metabolic syndrome and COVID-19 exacerbates the severity of COVID-19 outcomes in individuals with underlying metabolic conditions such as obesity, hypertension, diabetes, and dyslipidemia [15,16]. The pathophysiology involves chronic inflammation and altered angiotensin-converting enzyme 2 (ACE2) expression, which increases the susceptibility and severity of infection [16,17]. Studies have demonstrated that obesity impairs respiratory function and immune response, hypertension exacerbates endothelial dysfunction, and diabetes leads to chronic inflammatory states, all contributing to higher morbidity and mortality in patients with COVID-19 [17-19]. In addition, sex-specific differences play a role, as males generally exhibit higher rates of abdominal obesity and hypertension, whereas femalse often have lower HDL cholesterol levels [20]. These differences suggest that tailored interventions considering both metabolic syndrome and sex-specific risks are crucial in managing and mitigating the impacts of COVID-19.

An analysis of the prevalence of metabolic syndrome in the United States, as reported in the National Health and Nutrition Examination Survey (NHANES) 2011–2018, highlights its significant association with COVID-19. The study reported that approximately 34.7% of the adults had metabolic syndrome during this period. Among these, individuals with metabolic syndrome had higher rates of severe COVID-19 outcomes, including increased hospitalization and mortality rates, than those without metabolic syndrome [21]. Similarly, a European study examining 20,133 UK patients hospitalized with COVID-19 using the International Severe Acute Respiratory and Emerging Infection Consortium World Health Organization Clinical Characterization Protocol revealed a notable prevalence of metabolic syndrome components among patients with severe COVID-19. In this cohort, 56% of the patients had hypertension, 41% had obesity, and 21% had diabetes. The presence of these conditions was associated with a higher risk of intensive care unit admission and mortality [20]. These data emphasize the critical impact of metabolic syndrome on COVID-19 severity in diverse populations and underscore the importance of targeted public health strategies. In comparison with our data, which reported a significant increase in metabolic syndrome prevalence from 28.11% to 29.69% in South Korea during the COVID-19 pandemic, both the US and UK data further illustrate the global burden of metabolic syndrome and its exacerbating effect on COVID-19 outcomes. The increasing prevalence of obesity and metabolic syndrome is a global trend, independent of COVID-19, and South Korea has been no exception, especially since 2015 [22,23]. The increase in the prevalence of metabolic syndrome in the present study does not necessarily indicate that the impact of COVID-19 as a dominant factor. However, several factors contribute to metabolic syndrome, including sedentary lifestyle, physical inactivity, obesity, and mental stress [24,25]. Thus, it is undeniable that the COVID-19 pandemic has had a significant impact on these risk factors.

In this study, the most important factors contributing to the increased prevalence of metabolic syndrome after COVID-19 were abdominal obesity and elevated blood glucose levels. In males, abdominal obesity was more likely to contribute to metabolic syndrome in patients under 50 years of age, whereas in females, abdominal obesity contributed to metabolic syndrome in all age groups except the 60–69 years age group. Further, we found that regular physical activity levels were higher in younger age groups in the pre-COVID-19 era, and this pattern disappeared after COVID-19, indirectly suggesting that this trend may have contributed to the increase in abdominal obesity in males. In contrast, abdominal obesity did not differ significantly by age in females, and the effect of physical activity in younger females was not apparent; however, the higher prevalence of metabolic syndrome in middle-aged and postmenopausal females may explain this difference from males [26]. With regard to elevated fasting glucose levels, while there is a trend towards worsening glucose metabolism, especially in Asian patients [27], there is also evidence that decreased physical activity contributes to poor glycemic profiles [28]. Our results suggest that there are sex differences in the risk of fasting blood glucose elevations during COVID-19, with females showing significant elevations in the age ≥ 60 years group, while males tended to show elevated glucose levels that were not significantly related to age. Thus, it is conceivable that lifestyle changes due to physical inactivity or social distancing caused by COVID-19 may have contributed to the exacerbation of metabolic syndrome.

Other sex-specific differences observed in our study, such as higher rates of hypertension in males and lower HDL cholesterol levels in females, align with broader trends observed in studies conducted in the US and UK. The results of our study showed that female high-risk drinkers had a lower risk of metabolic syndrome, which is in contrast to the results in males. A previous study from South Korea analyzed the relationship between alcohol and metabolic syndrome and found that alcohol consumption of ≥ 14 g/day was associated with a increased risk of metabolic syndrome in both males and females [29]. Interestingly, this study showed that females aged 65 years or older who consumed alcohol had a lower risk of metabolic syndrome than non-drinkers of the same age, even if the amount of alcohol consumption increased, but this was not observed in males. Upon closer exploration, we found that the association was driven by improved lipid profiles such as low HDL and triglyceride levels, whereas abdominal circumference increased with alcohol consumption in this subgroup. Although we did not observe this association in our study, this suggests that alcohol consumption and the risk of metabolic syndrome may have different patterns depending on sex and age. Taken together, these findings highlight the necessity for comprehensive sex- and region-specific public health interventions to address metabolic syndrome in the context of COVID-19. In addition, follow-up studies are needed to determine whether the increase in metabolic syndrome and sex differences due to social and physical inactivity during COVID-19 will change again after the effects of COVID-19 have passed. Based on this, continued education and promotion of sex- and age-appropriate lifestyle modifications as preventive measures to manage metabolic syndrome risk factors are needed.

This study has several limitations. First, the cross-sectional design limited the ability to establish causality between the COVID-19 outbreak and changes in the prevalence of metabolic syndrome. The baseline characteristics of the study population differed in factors other than metabolic syndrome, which may have affected the results of the analysis. Second, the reliance on self-reported data for certain variables, such as smoking status and alcohol consumption, may have introduced a reporting bias. Third, the study population was limited to South Korea, which may have affected the generalizability of the findings to other populations with different demographic and healthcare characteristics. Fourth, the analysis did not account for potential confounding factors such as changes in diet or physical activity levels that could have occurred independently of the pandemic. Fifth, the household income data presented represent the distribution of survey subjects within quartiles rather than the actual changes in income amounts. This slight variation in income distribution and differences in other baseline characteristics, apart from metabolic syndrome, may have influenced the study results. Finally, given that the first confirmed case of COVID-19 in South Korea occurred on January 20, 2020, there is a limitation in that people surveyed between January 1 and 19, 2020, may have been classified into the post-COVID group, even though this was before the spread of COVID-19. Despite these limitations, our study analyzed a large population-based dataset and focused on sex-specific analysis of the COVID-19 pandemic, providing valuable insights into the sex-specific impact of the COVID-19 pandemic on metabolic health.

A novel finding of this study is the detailed sex-specific analysis of metabolic syndrome components and their relationship with COVID-19 outcomes, which has yet to be comprehensively addressed in previous research.

In conclusion, the COVID-19 pandemic has significantly increased the prevalence of metabolic syndrome primarily through increases in waist circumference and fasting glucose levels, with notable sex-specific differences. Males exhibited more significant increases in the metabolic syndrome components associated with smoking and high-risk drinking, whereas females showed significant variations in

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education level and household income. Clinicians should consider these sex-specific factors when developing targeted interventions to mitigate the impact of this pandemic on metabolic health.

KEY MESSAGE

1. The COVID-19 pandemic significantly increased the prevalence of metabolic syndrome, primarily through increases in waist circumference and fasting glucose levels, with notable sex-specific differences.
2. Males experienced significant increases in waist circumference and fasting glucose levels, while women showed variations influenced by education level, household income.
3. Sex-specific public health strategies are needed to address pandemic-related metabolic health risks.

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Conflicts of interest
The authors disclose no conflicts.

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Supplementary Table 1. Subgroup analysis for metabolic syndrome according to the sex, stratified by COVID-19 outbreak

Variable	Before COVID-19				After COVID-19			
	Male[a]	Female[a]	OR (95% CI)	*p* interaction	Male[a]	Female[a]	OR (95% CI)	*p* interaction
Age (yr)				< 0.001				< 0.001
< 65	1,116/3,453	594/3,581	0.42 (0.37-0.47)*		1,007/2,956	533/2,990	0.42 (0.37-0.47)*	
≥ 65	350/768	293/570	1.26 (1.02-1.57)*		334/704	242/477	1.14 (0.90-1.44)	
Education level				< 0.001				< 0.001
< University	889/2,348	717/2,439	0.68 (0.61-0.77)*		826/2,069	581/1,973	0.63 (0.55-0.72)*	
≥ University	577/1,873	170/1,712	0.25 (0.21-0.30)*		515/1,591	194/1,494	0.31 (0.26-0.38)*	
Household income				< 0.001				< 0.001
1st & 2nd quartile	560/1,569	490/1,617	0.78 (0.68-0.91)*		501/1,251	387/1,179	0.73 (0.62-0.86)*	
3rd & 4th quartile	906/2,652	397/2,534	0.36 (0.31-0.41)*		840/2,409	388/2,288	0.38 (0.33-0.44)*	
Smoking				< 0.001				< 0.001
Never	260/946	765/3,519	0.73 (0.62-0.86)*		239/869	659/2,935	0.76 (0.64-0.91)*	
Not never	1,206/3,275	122/632	0.41 (0.33-0.51)*		1,102/2,791	116/532	0.43 (0.34-0.53)*	
High-risk drinking				< 0.001				< 0.001
No	474/1,647	628/2,726	0.74 (0.65-0.85)*		452/1,424	564/2,311	0.69 (0.60-0.80)*	
Yes	992/2,574	259/1,425	0.35 (0.30-0.41)*		889/2,236	211/1,156	0.34 (0.29-0.40)*	
Physical activity				0.797				0.557
No	622/1,679	376/1,607	0.52 (0.45-0.60)*		585/1,488	326/1,294	0.52 (0.44-0.61)*	
Yes	844/2,542	511/2,544	0.51 (0.45-0.57)*		756/2,172	449/2,173	0.49 (0.43-0.56)*	

OR, odds ratios; CI, confidence interval.
[a]No. of patients with MetS/total no (%).
*Indicates statistical significance.

Supplementary Table 2. Baseline characteristics of study population according to sex and age group (cutoff 50 years old).

Variable	All population			Male			Female		
	19–49 yr	≥ 50 yr	*p* value	19–49 yr	≥ 50 yr	*p* value	19–49 yr	≥ 50 yr	*p* value
Sex			< 0.001						
Male	4,018 (48.73)	3,863 (53.26)		-	-		-	-	
Female	4,228 (51.27)	3,390 (46.74)		-	-		-	-	
Age (yr)	35.39 ± 8.88	62.65 ± 8.45	< 0.001	35.20 ± 8.85	63.42 ± 8.54	< 0.001	35.57 ± 8.91	61.77 ± 8.27	< 0.001
Education level			< 0.001			< 0.001			< 0.001
< University	3,353 (40.66)	5,476 (75.50)		1,704 (42.41)	2,713 (70.23)		1,649 (39.00)	2,763 (81.50)	
≥ University	4,893 (59.34)	1,777 (24.50)		2,314 (57.59)	1,150 (29.77)		2,579 (61.00)	627 (18.50)	
Household income			< 0.001			< 0.001			< 0.001
1st & 2nd quartile	2,305 (27.95)	3,311 (45.65)		1,105 (27.50)	1,715 (44.40)		1,200 (28.38)	1,596 (47.08)	
3rd & 4th quartile	5,941 (72.05)	3,942 (54.35)		2,913 (72.50)	2,148 (55.60)		3,028 (71.62)	1,794 (52.92)	
Smoking			< 0.001			< 0.001			< 0.001
Never	4,578 (55.52)	3,691 (50.89)		1,195 (29.74)	620 (16.05)		3,383 (80.01)	3,071 (90.59)	
Not never	3,668 (44.48)	3,562 (49.11)		2,823 (70.26)	3,243 (83.95)		845 (19.99)	319 (9.41)	
High-risk drinking			< 0.001			0.010			< 0.001
No	3,885 (47.11)	4,223 (58.22)		1,510 (37.58)	1,561 (40.41)		2,375 (56.17)	2,662 (78.53)	
Yes	4,361 (52.89)	3,030 (41.78)		2,508 (62.42)	2,302 (59.59)		1,853 (43.83)	728 (21.47)	
Physical activity			0.103			0.221			0.366
No	3,179 (38.55)	2,889 (39.83)		1,588 (39.52)	1,579 (40.87)		1,591 (37.63)	1,310 (45.16)	
Yes	5,067 (61.45)	4,364 (60.17)		2,430 (60.48)	2,284 (59.13)		2,637 (62.37)	2,080 (61.36)	
Waist circumference (cm)	81.67 ± 11.39	85.98 ± 9.20	< 0.001	87.35 ± 10.07	88.58 ± 8.40	< 0.001	76.28 ± 9.85	83.03 ± 9.18	< 0.001
Triglycerides (mg/dL)	127.80 ± 113.20	140.80 ± 11.20	< 0.001	159.10 ± 137.30	156.90 ± 130.40	0.467	98.01 ± 72.47	122.40 ± 80.26	< 0.001
HDL cholesterol (mg/dL)	53.90 ± 13.02	51.17 ± 12.83	< 0.001	48.87 ± 11.19	48.00 ± 11.79	0.001	58.68 ± 12.84	54.79 ± 13.01	< 0.001
Systolic BP (mmHg)	112.80 ± 13.06	124.10 ± 16.43	< 0.001	117.40 ± 12.17	125.20 ± 15.63	< 0.001	108.40 ± 12.38	122.70 ± 17.21	< 0.001
Diastolic BP (mmHg)	75.25 ± 10.20	76.53 ± 9.71	< 0.001	78.38 ± 10.13	77.52 ± 9.89	0.001	72.27 ± 9.33	75.39 ± 9.37	< 0.001
Fasting glucose (mg/dL)	95.91 ± 18.60	106.90 ± 24.95	< 0.001	96.62 ± 21.15	110.10 ± 26.96	< 0.001	93.34 ± 15.37	103.10 ± 21.87	< 0.001

Values are presented as number (%) or mean ± standard deviation.
HDL, high-density lipoprotein; BP, blood pressure.
The *p* value was derived by the chi-square test or independent t-test.

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Supplementary Table 3. Physical activity categorized by age, sex, and COVID-19

Category	All population			Male			Female		
	19–49 yr	≥ 50 yr	p value	19–49 yr	≥ 50 yr	p value	19–49 yr	≥ 50 yr	p value
Before Covid-19									
Physical activity			0.029			0.088			0.186
No	1,720 (38.17)	1,566 (40.51)		844 (38.54)	835 (41.11)		876 (37.82)	731 (39.84)	
Yes	2,786 (61.83)	2,300 (59.49)		1,346 (61.46)	1,196 (58.89)		1,440 (62.18)	1,104 (60.16)	
After Covid-19									
Physical activity			0.965			0.956			0.923
No	1,459 (39.01)	1,323 (39.06)		744 (40.70)	744 (40.61)		715 (37.40)	579 (37.23)	
Yes	2,281 (60.99)	2,064 (60.94)		1,084 (59.30)	1,088 (59.39)		1,197 (62.60)	976 (62.77)	

Values are presented as number (%).
The p value was derived by the chi-square test.