Predicting the Transition to Metabolically Unhealthy Obesity among Young Adults with Metabolically Healthy Obesity: A Nationwide Population-Based Study in South Korea

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Abstract

Background: Over 39% of individuals globally are obese. In addition to obesity, metabolic syndrome is regarded as a major contributor to non-communicable diseases, and the two are closely related. Given this relationship, the concepts of metabolically healthy and unhealthy obesity, considering the metabolic status, have been evolving. Attention is being directed to metabolically healthy obese individuals, who have relatively low transition rates to other chronic diseases. Particularly, as obesity rates continue to rise and unhealthy behaviors prevail among young adults, there is a growing need for obesity management that takes these metabolic statuses into account.

Objective: To identify demographic factors, health behaviors, and 5 metabolic statuses related to the transition from metabolically healthy obesity to unhealthy obesity among people aged 20 to 44 and to develop a screening tool to predict this transition.

Methods: This was a secondary analysis study using national health information data from the National Health Insurance System in South Korea. We analyzed the customized data using SAS and conducted logistic regression to identify factors related to the transition from metabolically healthy to unhealthy obesity. A nomogram was developed to predict the transition using the identified factors.

Results: There was a significant association between the transition from metabolically healthy to unhealthy obesity and male participants, those with the lowest socioeconomic status, smokers or current smokers, those consuming more than 30g/day of alcohol, those not exercising regularly, and those having abnormal metabolic factors. Each relevant variable was assigned a point value, and when the nomogram's total points reached 295, it was determined that the shift from metabolically healthy to unhealthy obesity had a prediction rate of greater than 50%.

Conclusions: The study identified risk factors for the transition of young adults from metabolically healthy to unhealthy obesity. A screening tool was developed using these risk factors to predict metabolically unhealthy obesity. The established nomogram enables prediction of the risk rate at which young adults with obesity may transition to metabolically unhealthy states, making it a valuable tool for interventions tailored to the needs of the target group.

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Predicting the Transition to Metabolically Unhealthy Obesity among Young Adults with Metabolically Healthy Obesity: A Nationwide Population-Based Study in South Korea

Abstract

Background
Globally, over 39% of individuals are obese. Metabolic syndrome, usually accompanied by obesity, is regarded as a major contributor to non-communicable diseases. Given this relationship, the concepts of metabolically healthy and unhealthy obesity considering the metabolic status have been evolving. Attention is being directed to the metabolically healthy people with obesity who have relatively low transition rates to noncommunicable diseases. As obesity rates continue to rise and unhealthy behaviors prevail among young adults, there is a growing need for obesity management that considers these metabolic statuses. A nomogram can be used as an effective tool to predict the risk of transitioning to metabolically unhealthy obesity from a metabolically healthy status.
Objective
The study aimed to identify demographic factors, health behaviors, and 5 metabolic statuses related to the transition from metabolically healthy obesity to unhealthy obesity among people aged 20–44 years and to develop a screening tool to predict this transition.
Methods
This secondary analysis study used national health data from the National Health Insurance System in South Korea. We analyzed the customized data using SAS and conducted logistic regression to identify factors related to the transition from metabolically healthy to unhealthy obesity. A nomogram was developed to predict the transition using the identified factors.
Results
Among 3,351,989 people, there was a significant association between the transition from metabolically healthy to unhealthy obesity and general characteristics, health behaviors, and metabolic components. Males showed a 1.30 higher odds ratio in transitioning to metabolically unhealthy obesity than females, and people in the lowest economic status were also at risk for the transition (odds ratio: 1.08, 95% confidence interval: 1.05–1.10). Smoking status, consuming >30 g of alcohol, and insufficient regular exercise were negatively associated with the transition. Each relevant variable was assigned a point value. When the nomogram total points reached 295, the shift from metabolically healthy to unhealthy obesity had a prediction rate of >50%.
Conclusions
This study identified key factors for young adults transitioning from healthy to unhealthy obesity, creating a predictive nomogram. This nomogram, including triglycerides, waist circumference, high-density lipoprotein-cholesterol, blood pressure, and fasting glucose, allows easy assessment of obesity risk even for the general population. This tool simplifies predictions amid rising obesity rates and interventions.

Keywords: metabolically healthy obesity, metabolic syndrome, metabolically unhealthy obesity, nomogram, obesity

Introduction

In the last 40 years, the number of people with obesity has more than tripled worldwide: as of

2016, 39% of the global population was estimated to have a body mass index (BMI) ≥25 kg/m^2 [1]. Obesity, usually accompanied by metabolic syndrome (MetS), is a major risk factor for noncommunicable diseases (NCDs), such as cancer, musculoskeletal problems, and cardiovascular diseases [2]. Epidemiological studies showed that 20%–45% of people have MetS. Furthermore, MetS prevalence is anticipated to increase to >50% by 2035 [3].

Recent studies have increasingly emphasized metabolically healthy obesity (MHO) and metabolically unhealthy obesity (MUO), with rising interest in the connection between obesity and MetS [4-6]. Studies revealed that individuals with MHO have a significantly reduced incidence of common obesity-related disorders, such as stroke, cancer, cardiovascular disease, and type 2 diabetes [7]. However, recent research indicates that individuals with MHO might eventually transition to MUO [6], with up to 50% of the population with obesity possibly falling into the MHO category [8]. This underlines the need for research and treatment to prevent or interrupt the transition from MHO to MUO.

On the other hand, young adults face higher mortality from obesity than older people.[2] As social relationships that foster independence evolve, the prevalence of unhealthy lifestyle behaviors, such as smoking, alcohol consumption, and physical inactivity, have been rapidly increasing, contributing to chronic diseases in the population with obesity [9, 10]. Additionally, the COVID-19 pandemic caused increased psychological stress, decreased physical activity, and altered eating patterns in young adults, contributing to obesity [11]. Young adults are more aware of obesity than older populations but engage less in weight loss programs and achieve less intentional weight loss [12], underscoring the need for proactive interventions and tailored programs for this age group.

This study identified risk factors and developed a screening tool with a nomogram to prevent the transition from MHO to MUO. A nomogram, a graphical tool that can perform a complicated approximal calculation, provided a clear interpretation of which predictors could be more critical factors [13]. The use of this scale also allows the general population to intuitively and easily assess the likelihood of transitioning to MUO. Therefore, this study aimed to predict the transition from MHO to MUO among young individuals with obesity using the nomogram.

Methods

Study Setting

The Korean government provides health check-ups for 97% of the South Korean population through public health insurance, while the remaining 3% receive these check-ups via medical aid programs. Residents are encouraged to undergo biennial health check-ups, covering measurements such as height, weight, BMI, blood tests, and urinary tests. The National Health Insurance System (NHIS) is tasked with collecting medical records, insurance statuses, and other pertinent data through these enrollment methods, providing corresponding services [14].

Measures

MHO and MUO are defined based on the metabolic status of the population with obesity. Obesity is characterized by an abnormal or excessive accumulation of adipose tissue, and BMI is primarily used to define it [1]. According to evidence regarding the high risk of type 2 diabetes or cardiovascular diseases with lower BMI standards, the WHO proposed each country make decisions about obesity definitions [15, 16]. Thus, the Korean Society for the Study of Obesity defined obesity as a BMI (weight in kg divided by the square of height in meters) ≥25 kg/m^2 [17]. Indicators for assessing metabolic status include waist circumference, fasting blood glucose levels, blood pressure, high-density lipoprotein (HDL) cholesterol levels, and fasting triglyceride (TG) levels. This study used the following cut-off points: ≥90 cm in men and ≥85 cm in women for waist circumference (a Korean-specific cut-off point) [17]; ≥130/85 mmHg or using antihypertensive medications for blood pressure; ≥100mg/dL or using antidiabetic medications for fasting blood glucose; ≥150 mg/dL for fasting triglycerides; and <40 mg/dL in men and <50 mg/dL in women for high-density lipoprotein (HDL) cholesterol [18]. An individual is defined as metabolically unhealthy if ≥3 of these 5 indicators yield abnormal results. Therefore, MUO is a state of obesity, having ≥3 abnormal indicators of metabolic status. Those who do not meet these criteria are defined as MHO [5].

In this study, healthy behaviors (smoking, alcohol consumption, and regular exercise), which are representative factors influencing MetS and obesity, were examined. Subjects were classified according to smoking status. Alcohol consumption was assessed by categorizing participants into individuals who consume alcohol heavily (heavy; ≥30 g/day), moderate alcohol (moderate; <30 g/day), and do not drink alcohol (none) [19]. Regular exercise was defined as engaging in high-intensity exercise for at least 20 minutes, ≥3 times per week, or moderate-intensity exercise for at least 30 minutes, ≥5 times per week [20].

Study Population

We identified subjects (age ≥20 years) who had health check-ups in 2009–2010 and 2013–2014. A total of 3,351,989 individuals were obese (BMI ≥25 kg/m^2) during both examinations. From this group, we excluded those who had MUO during the first examination and selected those aged 20–44 years during the second examination. We also excluded individuals diagnosed with cancer or cardiovascular diseases (myocardial infarction and stroke) prior to the second examination. After excluding missing values, the final sample size included in the analysis was determined to be 562,765 individuals.

Data Analysis

Young adults' general characteristics, health behaviors, and metabolic statuses were summarized using the Chi-square test and t-tests. We employed logistic regression analysis to examine the association between the transition to MUO and general characteristics, health behaviors, and metabolic states. Based on the results presented in Table 2, factors associated with the transition to MUO were identified, and scores were assigned ranging from 0 to 100. The prediction model for calculating the risk of the transition to MUO was depicted using a nomogram. P values <.05 were considered statistically significant. Statistical analysis was conducted using SAS, version 9.4 (SAS Institute Inc., Cary, NC, USA).

Ethical Consideration

The project was submitted for evaluation to the institutional review board (IRB) of Chung-Ang University (IRB no. 1041078-202203-HR-080). Since the study was a secondary analysis using the NHIS data, the IRB exempted the study from formal ethical approval. All subjects who underwent health check-ups through NHIS consented to provide the results and answers for research purposes. The data were deidentified by the NHIS and provided with permission.

Table 1. General characteristics of subjects according to metabolic status after 4 years

Characteristic	Total N=562,765 N (%) or M (SD)	Metabolically healthy obesity n=391,593 n (%) or M (SD)	Metabolically unhealthy obesity n=171,172 n (%) or M (SD)	*P*
General characteristics				
Sex, male	460,022 (81.74)	311,859 (79.64)	148,163 (86.56)	<.001
Age	37.39 (SD 4.87)	37.34 (SD 4.91)	37.52 (SD 4.78)	<.001
Income, Q1[a]	45,302 (8.05)	32,297 (8.25)	13,005 (7.6)	<.001
Smoking status				
Never	224,106 (39.82)	167,087 (42.67)	57,019 (33.31)	
Past	112,365 (19.97)	77,603 (19.82)	34,762 (20.31)	<.001
Current	226,294 (40.21)	146,903 (37.51)	79,391 (46.38)	
Alcohol consumption				
None	166,112 (29.52)	120,089 (30.67)	46,023 (26.89)	
Moderate	329,432 (58.54)	229,660 (58.65)	99,772 (58.29)	<.001
Heavy	67,221 (11.94)	41,844 (10.69)	25,377 (14.83)	
Regular exercise, yes	110,662 (19.66)	83,001 (21.2)	27,661 (16.16)	<.001
Body mass index, kg/m^2	27.77 (SD 2.33)	27.36 (SD 2.05)	28.71 (SD 2.65)	<.001
Waist circumference, cm	88.94 (SD 7.04)	87.34 (SD 6.55)	92.61 (SD 6.75)	<.001
Fasting glucose, mg/dL	96.02 (SD 16.79)	92.83 (SD 12.5)	103.32 (SD 22.21)	<.001
Systolic blood pressure, mm Hg	124.1 (SD 12.52)	121.48 (SD 11.67	130.08 (SD 12.35)	<.001
Diastolic blood pressure, mm Hg	78.4 (SD 9.34)	76.64 (SD 8.73)	82.43 (SD 9.46)	<.001
HDL-cholesterol [b], mg/dL	51.04 (SD 13.6)	53.04 (SD 13.64)	46.45 (SD 12.32)	<.001
Triglycerides[c], mg/dL	134.9 (95% CI 134.7–135.1)	115.6 (95% CI 115.4–115.8)	192.1 (95% CI 191.7–192.6)	<.001
Metabolic syndrome component (initial exam)				
Abnormal waist circumference	167,920 (29.84)	104,932 (26.8)	62,988 (36.8)	<.001
Abnormal fasting glucose	85,539 (15.2)	56,577 (14.45)	28,962 (16.92)	<.001
Abnormal blood pressure	180,849 (32.14)	117,449 (29.99)	63,400 (37.04)	<.001
Abnormal HDL-cholesterol [b]	79,524 (14.13)	51,530 (13.16)	27,994 (16.35)	<.001
Abnormal triglycerides	167,215 (29.71)	99,100 (25.31)	68,115 (39.79)	<.001
Metabolic syndrome component (after 4 years)				
Abnormal waist circumference	268,350 (47.68)	136,694 (34.91)	131,656 (76.91)	<.001
Abnormal fasting glucose	168,896 (30.01)	70,083 (17.9)	98,813 (57.73)	<.001
Abnormal blood pressure	246,816 (43.86)	120,013 (30.65)	126,803 (74.08)	<.001
Abnormal HDL-cholesterol [b]	136,472 (24.25)	53,000 (13.53)	83,472 (48.76)	<.001
Abnormal triglycerides	242,884 (43.16)	104,619 (26.72)	138,265 (80.78)	<.001

a Subject who got medical aid or was included in the lowest quartile of income
b HDL, high-density lipoprotein
c Geometric mean (95% Cl)

Results

General Characteristics and Metabolic Status of Subjects According to Metabolic Status after 4 Years

The general characteristics of subjects who transitioned from MHO to MUO over a 4-year period, compared to those who did not, are outlined in Table 1. A higher proportion of men was observed in the group that transitioned to MUO, with a statistically significant difference ($P < .001$). Age, income level, and health behaviors (smoking status, alcohol consumption, and regular exercise) showed statistically significant differences as well ($P < .001$). Both groups showed significant differences regarding the metabolic status based on the screening time point, even at the initial screening. Mainly, the group that transitioned to MUO exhibited remarkable changes in metabolic status, with variations in TG, fasting glucose, waist circumference, blood pressure, and HDL.

Logistic Regression Analyses of the Transition from MHO to MUO

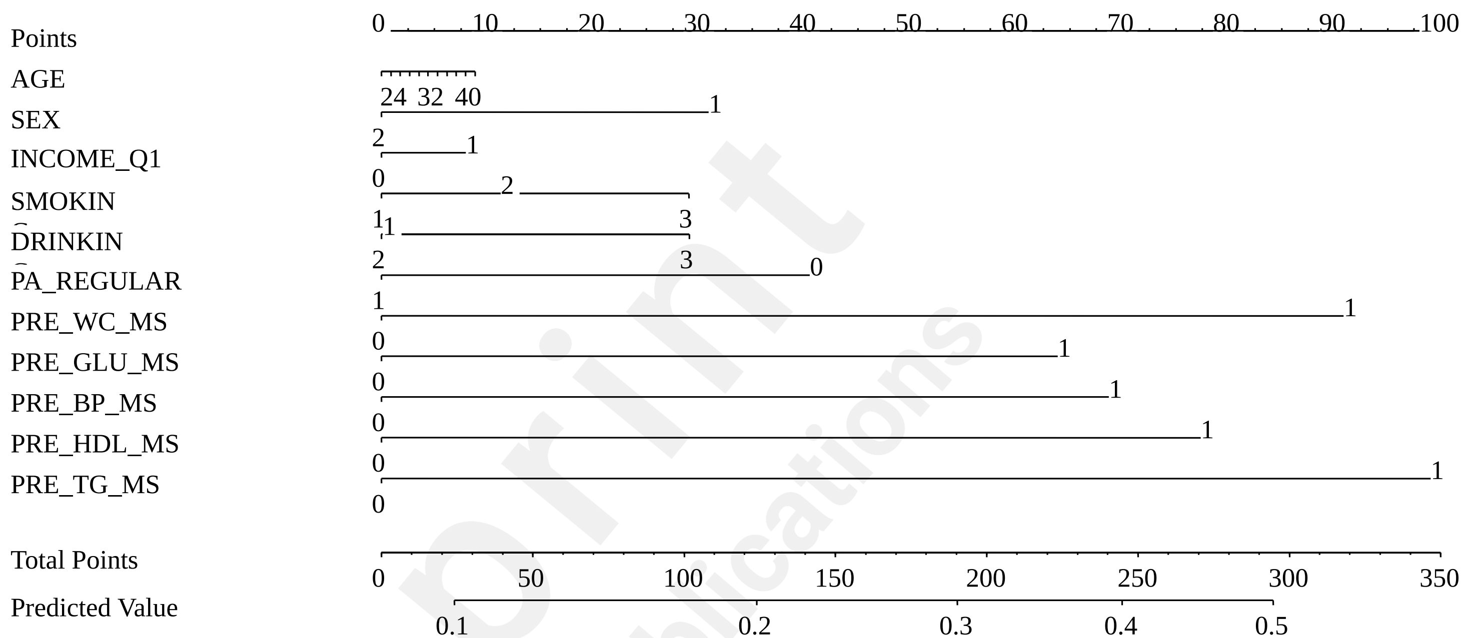
We identified factors contributing to the transition from MHO to MUO through logistic regression analysis. Adjusting for all significant characteristics identified in Table 1, we constructed the model 2. The model demonstrated that transitioning from MHO to MUO was independently associated with an increase in age. For each additional year of age, the odds ratio (OR) of transitioning to MUO was 1.04 times higher (95%, confidence interval [CI] 1.002–1.005). Males showed a 1.30 times higher OR of transitioning to MUO than females (95% CI 1.27–1.32). People belonging to the lowest economic group showed a 1.08 higher OR of transitioning to MUO than other economic status groups (95% CI 1.05–1.10). Regarding healthy behaviors, having a history of smoking and being a current smoker showed 1.10 (95% CI 1.09–1.12) and 1.27 (95% CI 1.25–1.29) higher OR of transitioning to MUO than people without a smoking history. Individuals consuming alcohol heavily had a 1.26 higher OR (95% CI 1.23–1.28) of transitioning to MUO compared to people not drinking alcohol. People participating in regular exercise had a 0.72 lower OR (95% CI 0.70–0.73) of transitioning to MUO than people not regularly exercising. Abnormal waist circumference at the initial screening (OR 2.11, 95% CI 2.08–2.14), impaired fasting glucose or related medication use (OR 1.69), hypertension or related medication use (OR 1.76, 95% CI 1.76–1.78), low HDL cholesterol or related medication use (OR 1.89, 95% CI 1.86–1.92), and elevated TG or related medication use (OR 2.25, 95% CI 2.22–2.28) were all statistically significantly associated with the transition to MUO.

Table 2. Logistic regression analysis of the transition from metabolically healthy obesity to metabolically unhealthy obesity.

Variable		n	Metabolic syndrome	%	Odds ratio (95% confidence interval)	
					Model 1[a]	Model 2[b]
General characteristics						
Age	Per 1 year				1.008 (1.006–1.009)	1.004 (1.002–1.005)
Sex	Male	460,022	148,163	32.21	1.65 (1.62–1.67)	1.30 (1.27–1.32)
	Female	102,743	23,009	22.39	1 (Ref.)	1 (Ref.)
Income [c]	Q1	45,302	13,005	28.71	0.92 (0.90–0.93)	1.08 (1.05–1.10)
	Q2–Q4	517,463	158,167	30.57	1 (Ref.)	1 (Ref.)
Smoking Status	Never	224,106	57,019	25.44	1 (Ref.)	1 (Ref.)
	Past	112,365	34,762	30.94	1.31 (1.29–1.33)	1.10 (1.09–1.12)
	Current	226,294	79,391	35.08	1.58 (1.56–1.60)	1.27 (1.25–1.29)
Alcohol consumption	None	166,112	46,023	27.71	1 (Ref.)	1 (Ref.)
	Moderate	329,432	99,772	30.29	1.13 (1.12–1.15)	0.99 (0.98–1.01)
	Heavy	67,221	25,377	37.75	1.58 (1.55–1.61)	1.26 (1.23–1.28)
Regular exercise	No	452,103	143,511	31.74	1 (Ref.)	1 (Ref.)
	Yes	110,662	27,661	25.00	0.72 (0.71–0.73)	0.72 (0.70–0.73)
Metabolic syndrome component (first exam)						
Waist circumstance	No	394,845	108,184	27.40	1 (Ref.)	1 (Ref.)
	Yes	167,920	62,988	37.51	1.59 (1.57–1.61)	2.11 (2.08–2.14)
Fasting glucose	No	477,226	142,210	29.80	1 (Ref.)	1 (Ref.)
	Yes	85,539	28,962	33.86	1.21 (1.19–1.23)	1.69 (1.66–1.72)
Blood pressure	No	381,916	107,772	28.22	1 (Ref.)	1 (Ref.)
	Yes	180,849	63,400	35.06	1.37 (1.36–1.39)	1.76 (1.74–1.78)
HDL[d]-cholesterol	No	483,241	143,178	29.63	1 (Ref.)	1 (Ref.)
	Yes	79,524	27,994	35.20	1.29 (1.27–1.311)	1.89 (1.86–1.92)
Triglycerides	No	395,550	103,057	26.05	1 (Ref.)	1 (Ref.)
	Yes	167,215	68,115	40.73	1.95 (1.93–1.98)	2.25 (2.22–2.28)

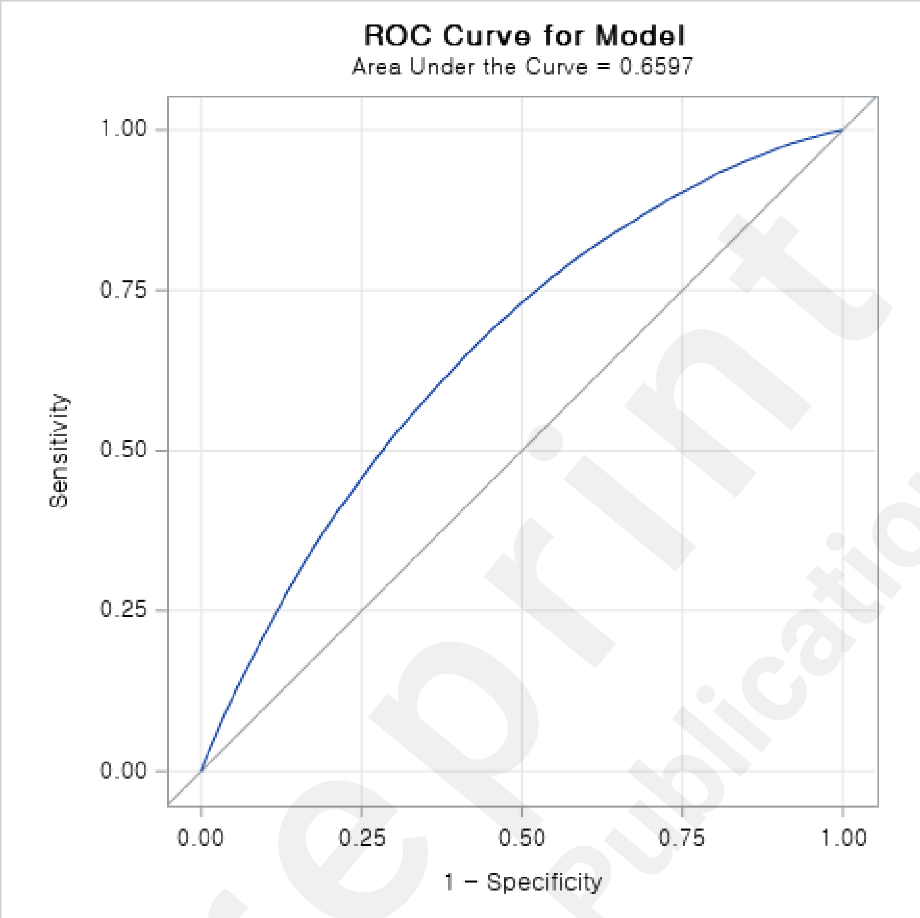
* All variables had a statistically significant association with the transition to metabolically unhealthy obesity (P<.001)
a Model 1. Unadjusted
b Model 2. Adjusted for age, sex, income, smoking, drinking, regular exercise, waist circumstance, fasting glucose, blood pressure, HDL-cholesterol, and triglycerides
c Q1–Q4, first through fourth quartiles
d HDL, high-density lipoprotein

Figure 1. The nomogram for predicting the transition from metabolically healthy obesity to metabolically unhealthy obesity



* Sex: 1 (male), 2 (female)
Income_Q1: 0 (Q2–4), 1 (Q1)
SMOKIN: smoking status, 1 (never), 2 (past), 3 (current)
DRINKIN: alcohol consumption, 1 (none), 2 (moderate), 3 (heavy)
PA_REGULAR: regular exercise, 0 (yes), 1 (no)
PRE_WC_MS, PRE_GLU_MS, PRE_BP_MS, PRE_HDL_MS, PRE_TG_MS: 0 (normal), 1 (abnormal)

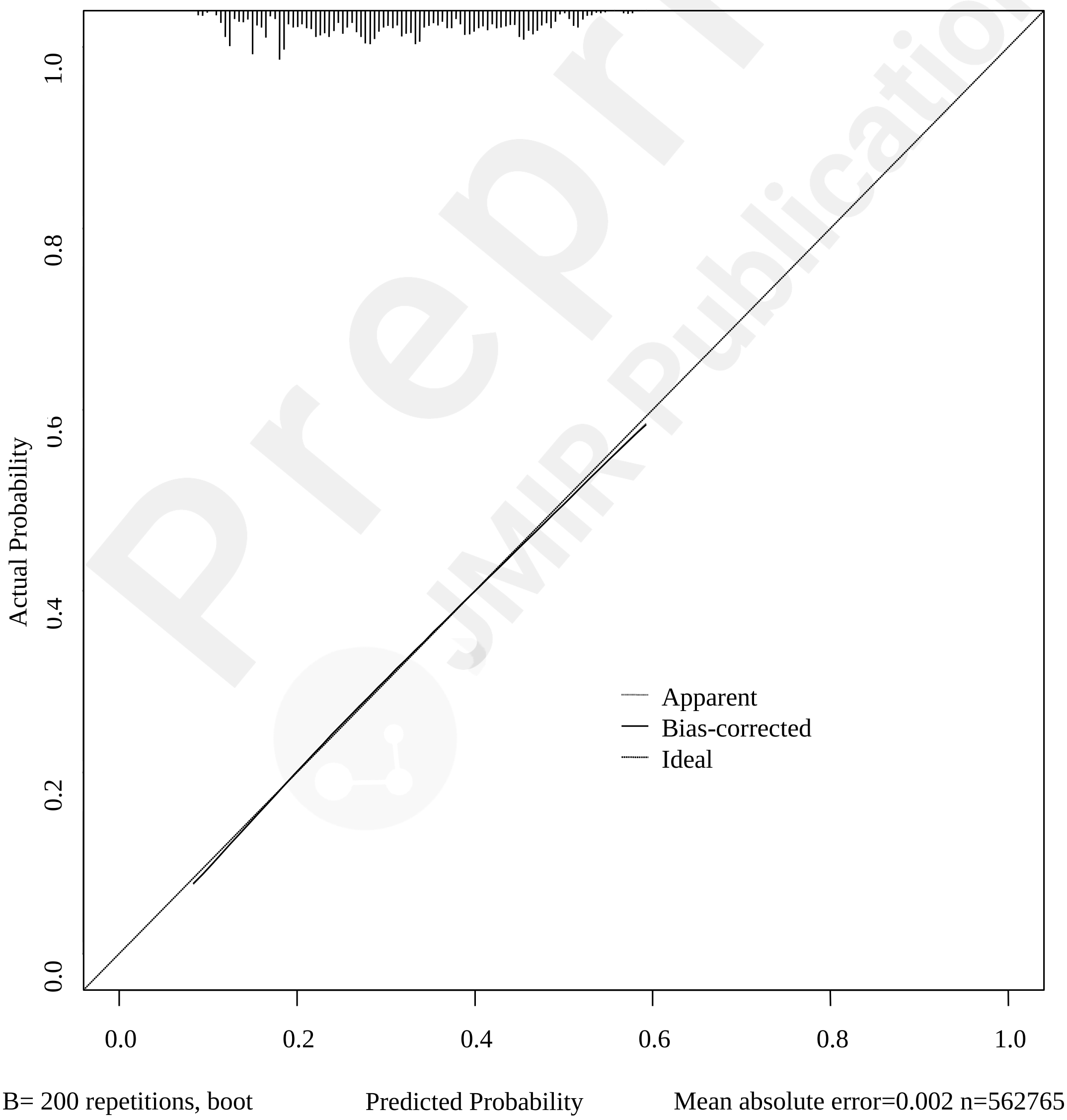
Figure 2. A receiver operating characteristic curve of the nomogram (model 2)



Prediction of the Transition from MHO to MUO

A nomogram (Figure 1) was constructed to assist clinical predictions, providing a quantitative estimation of the probability of transitioning to MUO. This is a screening tool for predicting the transition from MHO to MUO. According to individual characteristics, each value is located based on each variable in the nomogram. At each variable point, a vertical line is drawn up to the scale of "Points," followed by identifying the point of the variable. After marking all values based on variables, all points of each variable are summarized, and the point on the scale of "Total Points" is marked. At the total point, after drawing a vertical line to the scale of "Predicted Value," the matched point will be the individual's predicted value of transitioning from MHO to MUO. Using multivariate logistic regression, we identified 11 independent predictors, assigning the highest score in the nomogram to each variable (e.g., 44 years: 9 points, male: 32 points, first income level quartile: 9 points, current smoker: 29 points, heavy drinker: 29 points, no regular physical activity: 41 points, abnormal waist circumference: 92 points, abnormal fasting glucose or taking diabetes medications: 65 points, abnormal blood pressure or taking hypertension medication: 70 points, abnormal HDL level or taking dyslipidemia medications: 78 points, abnormal serum TG level or taking dyslipidemia medication: 100 points, total points: 344 points). When the total points reached 295, the prediction rate for transitioning from MHO to MUO was determined as >50%. As depicted in Figure 3, the nomogram showed close agreement between predicted and observed outcomes in the study population, with a slight tendency for overestimation in the 0.1–0.2 and 0.5–0.6 intervals. Figure 2 shows the receiver operating characteristic curve used to validate the nomogram, yielding an area under the curve of 0.66 (95% CI 0.658–0.661).

Figure 3. The calibration curves for the nomogram for predicting the transition from metabolically healthy obesity to metabolically unhealthy obesity. The dotted line represents the ideal concordance between the predicted and actual probability. The solid line represents the performance of the nomogram.



Discussion

Principal Findings

The prevalence of obesity is escalating globally, accompanied by MetS, increasing the risk of NCDs. This upward trend among young adults can be attributed to lifestyle alterations during adulthood [10] and, more recently, decreased physical activity or changed dietary habits due to the COVID-19 pandemic [11]. Moreover, individuals with MUO face substantially elevated risks of NCDs compared to those with MHO [4]. Considering that MHO might merely represent a "honeymoon phase" preceding the shift to MUO [6], the urgency of managing MHO among young adults is underscored.

This study investigated the influence of sociodemographic factors, metabolic status, and health behaviors on MetS development. By comparing young adults who transitioned from MHO to MUO with those who maintained their health status, we identified associations between the transition and factors with gender, low socioeconomic status, 5 metabolic variables, and health-related behaviors (drinking, smoking, and irregular physical activity). The nomogram was constructed to predict the transition from MHO to MUO using the data from the results.

Transitioning to MUO was higher in males than in females. In a previous study, MetS prevalence based on gender showed various results according to age. A cross-sectional study using data from the Third National Health and Nutrition Examination Survey in America showed a similar result to this study: a higher prevalence of MetS in male individuals [21]. However, they identified that women showed a higher MetS prevalence than men in older age. Using the same perspective, a cohort study from Switzerland reported that the gender-based prevalence of MetS could be different according to the age range [22]. In Korea, the MetS fact sheet of 2010 using the data from the Korean National Health and Nutrition Examination Surveys (KNHANES) from 2007 to 2018 reported a higher prevalence in the male population but increasing trends in the female population aged >70 years [23]. Thus, our subjects were restricted to young adults. Additionally, the results of this study were similar to that of previous studies. Regarding economic status, individuals with lower income levels showed a compatibly higher risk of transitioning to MUO, aligning with previous studies on risk factors for MetS development [24. 25]. Our findings align with the reality that obesity is more prevalent than underweight, especially in low-income countries [1]. Furthermore, dietary issues in these regions correlate with diet-related noncommunicable diseases [1]. Consequently, the findings emphasize the need to consider gender and the importance of healthcare provision for those in low socioeconomic positions within the community in the management of individuals with MHO to prevent transitioning to MUO.

The associations between obesity and health behaviors, i.e., smoking status [26], alcohol consumption [27], and physical activity [28], have been widely investigated and linked to MetS [29]. Our study further validated the significance of health-related behavior patterns in the transition from MHO to MUO in young adults with obesity. We found that moderate alcohol consumption (<30 g of alcohol daily) was associated with a decreased transition to MUO. Similar to this result, some research [30] indicated a positive correlation between moderate alcohol consumption and a reduced risk of MetS. However, a study targeting Asian populations indicated that even moderate alcohol intake might affect metabolic status [31]. Recognizing that alcohol consumption itself could affect dietary habits in the population with obesity, as well as the possibility that the frequency of alcohol consumption might influence the occurrence of MetS more than the quantity consumed, is crucial [32]. Therefore, a particular caution, including restricting the frequency of consumption, is required regarding alcohol consumption to prevent the onset of MetS in patients with obesity.

We found that abnormal metabolic factors played a crucial role in the transition to MUO over a 4-year span. Specifically, abnormal waist circumference and TG levels showed nearly ≥2 higher ORs for the transition to MUO. Waist circumference was recognized as a more pertinent obesity measure than BMI [33] and is frequently employed to forecast cardiometabolic disorders [34]. Waist circumference is strongly linked to abnormal fasting glucose [35] and lipid profiles [36], both affecting metabolic states. Our findings underscore the importance of waist circumference control by demonstrating its association with the development of MUO, with an OR >1.6 for other abnormal metabolic variables. Unlike other metabolic conditions that might demand pharmacological management, waist circumference is a physical attribute that can be reduced through lifestyle changes, such as exercise, dietary adjustments, and curbed alcohol consumption [37]. Managing waist circumference is not only a strategy for combating obesity but also for improving other abnormal metabolic disorders [37]. Therefore, tailored interventions aimed at trimming waist circumference are essential. Additionally, our findings revealed a pronounced association between TG levels and the transition to MUO, connecting high TG levels with prevalent issues such as type 2 diabetes and abnormal HDL in people with obesity [38]. Approximately 15 years ago, a cross-sectional study in America revealed that abnormal TG and HDL levels were one of the most prevalent MetS combination factors in young males and females [39]. Still, the research even proposed TG levels and waist circumference as specific indicators for predicting MetS in African Americans [40]. For individuals with MHO with abnormal metabolic factors, proactive management, possibly including medication control and lifestyle modifications, is vital. More intensive interventions might be warranted in abnormal waist circumference and serum TG cases.

The nomogram was developed with identified factors, predicting the transition from MHO to MUO. As a simplified tool [13], the nomogram allows young adults with MHO to directly calculate their risk of transitioning to MUO with their health examination results. Created using data from the NHIS, it can serve as a valuable resource for adults undergoing regular health check-ups, enabling them to assess their risk and formulate personalized health plans. Individuals can easily evaluate their risk without relying on healthcare professionals or medical experts. People with MHO can efficiently use this tool to tailor their interventions by entering their gender, health behaviors, and metabolic status scores into the nomogram.

Limitations

The study had some limitations as a secondary analysis of Korean health examination data. Although dietary habits or nutrition consumption are critical factors for obesity or MetS, we could not include them as variables since we used publicized NHIS data. Second, while clinical measurements were accurately performed in a hospital setting, health behavior results—obtained through self-response surveys—might be subjective. Third, further validation for other racial groups is needed. Differences in obesity [41] and MetS [42] prevalence among various races or ethnicities necessitate cautious adaptation and validation for broader applicability.

The other limitation of the nomogram is that prediction variables are multifaceted, comprising several modifiable factors that interact. Since changes in one variable can influence other variables, predicting outcomes based on single-variable changes can be intricate. However, enhancing these factors and embracing healthy behaviors can lead to improved metabolic status and potentially aid obesity mitigation.

Despite the limitations, a comprehensive analysis was conducted using the data of all subjects with obesity in South Korea over 4 years. The study and the developed nomogram can be applied generally to Koreans to predict the transition to MUO. For the next step, the research can be extended to people without obesity, finding associations between MHO and MUO and comparing risk factors among them. Since the nomogram can show intuitive results of predictions and be interpreted easily by any readers [13], it can be broadly used as a screening tool, leveraging national-level examination results. Coupled with advancements in digital health, telehealth, and wearable devices [43], this screening tool, targeting metabolic status, will play an essential role in directing appropriate interventions to those in need.

Conclusions

This study explored the dynamics of young adults with obesity in South Korea, pinpointing factors that correlate with the transition from MHO to MUO and creating the predictive nomogram. In our study, the scoring arrangement for transitioning to MUO revealed that the major variables were TGs, waist circumference, HDL cholesterol, blood pressure, and fasting glucose. Although these risk factors were highlighted in previous studies [33-36], the significance of our study lies in the development of the nomogram that enables even the general population to easily and intuitively assess their likelihood of transitioning to MUO.

With the rising prevalence of obesity and increasing intervention strategies, our screening tool simplifies the prediction using easily identifiable factors for the general population. However, this study serves as a starting point, and further research should broaden models to include racial characteristics, thereby improving the relevance of the nomogram across diverse populations.

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Data Availability

The data sets generated and/or analyzed during this study are not publicly available because of the NHIS regulation [44]. The customized database used in this study was formatted by the NHIS in Korea, which strictly prohibits sharing the data publicly. Only permitted researchers can access the dataset, and analysis can only be performed in the designated data center.

Conflicts of Interest

None

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Abbreviations

BMI, body mass index
HDL, high-density lipoprotein
MetS, metabolic syndrome
MHO, metabolically healthy obesity
MUO, metabolically unhealthy obesity
NCD, non-communicable disease
NHIS, National Health Insurance Service
OR, odds ratio
TG, triglyceride

Data Availability

This research used a customized database from South Korea's National Health Insurance Service (NHIS). Comprehensive details about the dataset, including access protocols, can be obtained through the NHIS's designated website.[44]

Supplementary

Table 1 Relative risk of the transition from metabolically healthy obesity to metabolically unhealthy obesity.

Variable		N	METS	Percent	OR(95% CI)		RR(95% CI)	
					Model 1	**Model 2**	**Model 1**	**Model 2**
Age	per 1yrs.				1.008 (1.006-1.009)	1.004 (1.002-1.005)	1.005 (1.004,1.006)	1.002 (1.001,1.003)
Sex	Male	460022	148163	32.21	1.65 (1.62-1.67)	1.30 (1.27-1.32)	1.44 (1.42-1.46)	1.21 (1.19-1.23)
	Female	102743	23009	22.39	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
Income	Q1	45302	13005	28.71	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
	Q2-Q4	517463	158167	30.57	0.92 (0.90-0.93)	1.08 (1.05-1.10)	0.94 (0.92-0.96)	1.05 (1.03-1.07)
SMOKING	Non	224106	57019	25.44	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
	Ex	112365	34762	30.94	1.31 (1.29-1.33)	1.10 (1.09-1.12)	1.22 (1.20-1.23)	1.07 (1.06-1.09)
	Current	226294	79391	35.08	1.58 (1.56-1.60)	1.27 (1.25-1.29)	1.38 (1.36-1.39)	1.17 (1.15-1.18)
DRINKING	Non	166112	46023	27.71	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
	Mild	329432	99772	30.29	1.13 (1.12-1.15)	0.99 (0.98,1.07)	1.09 (1.08-1.11)	0.99 (0.98-1.01)
	Heavy	67221	25377	37.75	1.58 (1.55-1.61)	1.26 (1.23-1.28)	1.36 (1.34-1.38)	1.15 (1.13-1.17)
PA_REGULAR	No	452103	143511	31.74	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
	Yes	110662	27661	25.00	0.72 (0.71-0.73)	0.72 (0.70-0.73)	0.79 (0.78-0.80)	0.80 (0.79-0.81)
Metabolic syndrome component (1st Exam)								

WC_MS	No	394845	108184	27.40	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
	Yes	167920	62988	37.51	1.59 (1.57-1.61)	2.11 (2.08-2.14)	1.37 (1.36-1.38)	1.68 (1.66-1.70)
GLU_MS	No	477226	142210	29.80	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
	Yes	85539	28962	33.86	1.21 (1.10-1.23)	1.69 (1.66-1.72)	1.14 (1.12-1.15)	1.46 (1.44-1.48)
BP_MS	No	381916	107772	28.22	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
	Yes	180849	63400	35.06	1.37 (1.36-1.39)	1.76 (1.74-1.78)	1.24 (1.23-1.26)	1.50 (1.48-1.51)
HDL_MS	No	483241	143178	29.63	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
	Yes	79524	27994	35.20	1.29 (1.27-1.31)	1.89 (1.86-1.92)	1.19 (1.17-1.20)	1.57 (1.55-1.59)
TG_MS	No	395550	103057	26.05	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
	Yes	167215	68115	40.73	1.95 (1.93-1.98)	2.25 (2.22-2.28)	1.56 (1.55-1.58)	1.74 (1.72-1.76)

Model1 Non-adjusted
Model2 AGE SEX INCOME_Q1 SMOKING DRINKING PA_REGULAR PRE_WC_MS PRE_GLU_MS PRE_BP_MS PRE_HDL_MS PRE_TG_MS