Honam Mathematical J. **43** (2021), No. 4, pp. 717–739
https://doi.org/10.5831/HMJ.2021.43.4.717

THE DEVELOPMENT OF AN OBESITY INDEX MODEL AS A COMPLEMENT TO BMI FOR ADULT: USING THE BLOOD DATA OF KNHANES

Kwanghee Ko and Chunyoung Oh*

Abstract. We used blood data to predict obesity by complementing the BMI risk, because some blood factors are significantly associated with obesity. For the sampling method, a two-step stratified colony sampling method was used based on sixteen blood factors collected by the Korea National Health and Nutrition Examination Survey(KNHANES). We identify the number of effective blood data of obesity in the final model as $6 \sim 8$ factors that differ somewhat depending on age and gender. Also, the coefficient of determination that represents the predictive power of obesity in the regression model is the highest for both men and women of aged 19 and in their 20s and 30s, and the predictive power decreases with increasing age.

1. Introduction

Obesity is recognized as a major global public health issue. The factors that lead to obesity are highly diverse. The factors that contribute to obesity include genetics, environment, unhealthy diet, and sedentary lifestyle. Several studies have shown that risk factors associated with obesity include chronic stress, waist circumference, malnutrition, low physical activity, consumption of food with a high glycemic index, a reduced amount of sleep, as well as alcohol consumption and dietary habits [1], [9], [16], [26], [27], [32]. This suggests a vicious circle, where increased glucocorticoid action, obesity, and stress interact with and amplify each other [38].

The Quetelet Index was described in 1832, and was termed the Body Mass Index (BMI) in 1972 by Ancel Keys. This index is the ratio of the weight in kilograms divided by the square of the height in meters [17]. To define obesity, the BMI is used far more commonly than body fat percentage. Keys [48] judged

Received September 22, 2021. Revised October 29, 2021. Accepted October 30, 2021.
2010 Mathematics Subject Classification. 92B10, 62C, 92B11.
Key words and phrases. Obesity, BMI, Blood data, KNHANES,coefficient of determination, multicollinearity .
Chunyoung Oh was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(2020R1I1A306562711).
*Corresponding author

BMI as appropriate for population studies, while inappropriate for individual evaluation. Additionally, the relation between BMI and the percentage of body fat is not linear and differs for men and women [39].

Nick [42] has proposed a new formula for computing Body Mass Index that accounts for the distortions of the traditional BMI formula for shorter and taller individuals. He explains that the BMI leads to confusion and misinformation. Some elderly persons who are portly but have low muscle mass have normal or even low BMI scores, an underestimation of body fat. Also, lean persons with high muscle mass, such as athletes, sometimes have high BMI scores, an overestimation of body fat.

Generally, obesity is classified as a BMI measurement, but the validity of this assumption has been investigated according to race and gender. There has been much discussion about whether BMI is appropriate for determining whether Asians are obese or not [10], [18]. There is not always a direct and clear correlation between total body fat and risk for obesity-related conditions [49]. This means that BMI alone may be insufficient for determining the risk of serious conditions.

Heymsfield et al.[18] added waist circumference (WC) as a means of expanding the generalizable features of adult human shape. Waist circumference can also be used as a complementary measurement tool to give additional information on body fat to individuals within the healthy weight range wanting to build muscle or improve their diet. Lemieux et al. [30] demonstrated that the threshold value of WC corresponding to excess visceral fat may differ by age, sex, and degree of obesity. Even though WC has been reported to be a better indicator of obesity-related risk than BMI, the major limitation of the WC measure is the great inter-ethnic variability that exists [49].

Also, the waist-to-hip ratio(WHR) could be used as an alternative indicator for obesity in young adults in the central south of China [46]. Therefore, there is not always a direct and clear correlation between total body fat and risk for obesity-related conditions. Naturally, different ethnicities have different body builds and proportions. Each measurement has its own strengths and weaknesses, and each identify different aspects of obesity [49].

Although weight and height are clearly direct and important factors in determining whether obesity is present, it may be difficult to determine obesity based sole on BMI. Also, the use of a single index of BMI in the diagnosis of obesity may not be enough, because of the sensitivity of BMI, and the vast difference in the ratio of fat among individuals.

Nevill et al. showed that younger people had greater BMI than older people for the same levels of adiposity, and concluded that it was necessary to adjust the BMI threshold according to age and gender [34]. Rothman mentions the fact that the BMI does not take into account the difference between fat and nonfat mass such as bone and muscle, the changes in body composition that occur with age, and the time relation between obesity and the outcome being measured [39].

Nevertheless, due to its simplicity, the most widely used method to check if an individual is a healthy weight is their body mass index. This means that there is a need to conduct further complementary study.

The purpose of this study is to predict or determine obesity by investigating the relationship between BMI and blood factors. In other words, the purpose of this study is to develop a statistical regression model that determines the dependent variable, BMI, using the factors of blood test data that were collected by the Korea National Health and Nutrition Examination Survey (KNHANES) as independent variables. The KNHANES is one of the principal sources for investigating obesty in the population with vast amounts of variables and data related to obese diseases. Since there may be differences in obesity according to gender and age, an independent model is implemented according to gender and age.

1.1. Related Work

For the blood data included in NHANES, we review the related works. Some studies have shown that individual factors are associated with BMI, while some studies have demonstrated that multiple blood factors are associated with BMI or obesity.

Zou et al.[47] showed that there is a significant correlation between triglycerides(TGs) and ectopic fat obesity and that there is an inverted U-shaped curve association between them. Fasting serum glucose shown to have a little stronger positive correlation with BMI. Both obese male and female persons showed higher levels of fasting serum glucose and glycosylated hemoglobin [14]. Also, Akter et al. found that fasting serum glucose is significantly increased in both male and female obese persons [2].

Overweight, obese, and morbidly obese females had significantly elevated platelet counts compared with normal-weight females [15], [23]. Johanna et al. took care to review the mechanisms driving an inflammatory state and the effect of obesity on white blood cells(WBC), red blood cells(RBC), platelets, and thrombotic risk. There is an observed relative, and sometimes absolute leukocytosis driven by this inflammatory state [23]. A study by Pratley et al.[37] indicates that age, race, and obesity are significantly associated with the WBC count in healthy individuals. Obesity is associated with increased red blood cell, and RBC folate increased incrementally with BMI. Waist circumference, serum triglycerides, and fasting plasma glucose each displayed significant positive relations with RBC folate [24].

ALT(SGPT)is known to be associated with obesity [4], [41] and obesity has been reported as a major risk factor for developing non-alcoholic fatty liver disease(NAFLD)[28], [33]. Yesmin et al. described that hemoglobin concentration is significantly increased in both male and female obese individuals [3]. Obese outpatients with type 2 diabetes have a higher HbA1c mean value and higher risk of Uncontrolled glycemia (UCG) than subjects with normal body weight [19]. Cheng et al. showed that BMI, fasting glucose, cholesterol, alanine

aminotransferase (ALT)levels, and platelet counts were positively associated, while hepatitis B surface antigen (HBsAg) positivity was inversely associated with fatty liver, especially for subjects with BMI$> 22.4kg/m^2$ and age > 50 years [8].

Uric acid(UA) is an end product of purine metabolism in the human body. Elevated serum uric acid(SUA) can not only lead to gout, but is also an essential risk factor of obesity, which may result in increased incidence of metabolic syndrome [12]. In the whole group of athletes, a positive correlation between serum creatinine and BMI was found [6], but we could not find a relation with the general population. In a study of Chinese male steel workers, Jean et al. described that an increased RBC count was associated with obesity, and increased hematocrit(Ht) was associated with smoking, poor sleep, and obesity. Higher WBC count, RBC count, hemoglobin(Hb), and hematocrit were associated with obesity [22].

BMI is implicated as a strong risk factor of elevated ALT in non-diabetic Korean adults [29]. In adults aged 17 year and older from the NHANES III($1988 - 1994$), elevated ALT or AST of unexplained origin was significantly associated with high BMI and large waist circumference [31].

However, in the analysis of Walton et al., neither age nor adiposity was significantly correlated with any serum lipid or lipoprotein concentration [44], and they failed to detect any relation between BMI and cholesterol. In the study of a North-East Italy general population, [5] demonstrated that obesity per se is not independently associated with altered RBC, Hb and hematocrit(Ht). Jang et al. described that no significant differences in the BMI and fasting blood glucose level were found between the anti-HCV-antibody-positive and non-infected groups [21]. We could not find in the literature where a blood urea nitrogen(BUN) level was directly associated with BMI.

Studies still demonstrate the association between a few blood factors and obesity or BMI. The Rabindra Nath Das reports identifies the determinants of diabetes mellitus and obesity based on six blood serum measurements along with the age, sex, average blood pressure, and body mass index on diabetes patients. He showed mean BMI increases as the average blood pressure or Low Density Lipoproteins(LDL) increases. Impacts of blood serum along with age, sex, and the average blood pressure determined obesity [40].

Brown et al. described and evaluated the relationships between BMI and blood pressure, cholesterol, high-density lipoprotein-cholesterol (HDL-C), and hypertension and dyslipidemia. They showed that at ages younger than 60 years as BMI increased, the prevalence of high blood pressure and mean levels of systolic and diastolic blood pressure increased. As levels of BMI increased, the rates of low HDL-C increased and mean levels of HDL-C decreased [11].

We investigate the relation between BMI and sixteen blood factors in the KNHANES. The results in our paper and the cited studies could be utilized in obesity prediction, and can be included as inference tools for obesity.

2. Material and Methods

2.1. Data source

The National Health and Nutrition Examination Survey(NHANES) calculates nationally representative statistics on the national health level, health behavior, and food and nutrition intake.

From 1998, this survey was implemented every three years; from 2007, the survey is now implemented every year. Its purpose is to provide basic data for health policy, such as goal setting, evaluation of the comprehensive national health promotion plan, and development of the health promotion programs. The KNHANES is an ongoing survey of the general Korean population conducted by the National Center for Health Statistics within the Centers for Disease Control and Prevention. The KNHANES uses the most recent Population and Housing Census data available at the time of sample design as a basic extraction frame to extract a representative sample for Koreans aged 1 year or older living in Korea. To use the latest information that can be reflected, the basic extraction frame was supplemented by adding the public housing price data and the population inclusion rate was improved.

For the sampling method, a two-step stratified colony sampling method was used with the survey district and household as the primary and secondary sampling unit, respectively. For the 7th survey $(2016-2018)$, cities, provinces, and housing types, and the ratio of the residential area and the educational background of the household are used as the implicit stratification standard.

The health interview survey investigates morbidity, medical use, activity restrictions, education and economic activity, while physical activity, and the health behavior survey (self-reported survey) examines smoking, drinking, mental health, safety awareness, oral health, etc. However, the survey questions differ according to age. The KNHANES participants undergo a survey as well as a medical examination that includes blood examination and measurement of height and weight. Responses to questions were obtained directly from those aged 16 years or older; all others were obtained from the parent or guardian.

Physical measurement, blood pressure and pulse measurement, blood and urine test, oral test, lung function test, eye test, and grip strength test are included in the examination. This survey is administered by the Ministry of Health and Welfare and the Korea Centers for Disease Control and Prevention.

In this study, we use the 2018 data for analysis. We examined the association between the variables through variables of blood test data and BMI among adults in Korean adults aged 19 or older.

2.2. Model Classification

In the 2018 year, $7,992$ people participated in KNHANES. We first determined $6,489$ people ≥ 19, and then determined $6,170$ as the final study population, excluding 319 who did not respond to obesity prevalence.

TABLE 1. Prevalence of obesity by gender (Total)

Obesity / Age	Underweight	Normal	Pre-obesity	Obesity stage 1	Obesity stage 2	Obesity stage 3	Total
Male	51	849	696	962	141	20	2719
(%)	1.88	31.22	25.6	35.38	5.19	0.74	
Female	164	1551	717	839	155	25	3451
(%)	4.75	44.94	20.78	24.31	4.49	0.72	
Total	215	2400	1413	1801	296	45	6179

The KNHANES classifies obesity prevalence into six categories using BMI: $BMI < 18.5$ is underweight, $18.5 \leq BMI < 23$ is normal, $23 \leq BMI < 25$ is pre-obesity, $25 \leq BMI < 30$ is obesity stage 1, $30 \leq BMI < 35$ is obesity stage 2, and $35 \leq BMI$ is obesity stage 3. However, for those under the age of 19, although the BMI is measured, it does not determine the obesity prevalence. Table 1 show the prevalence of obesity by gender for the final research population.

For this paper, we utilized chi-square because this statistical test performs well at evaluating sets of categorical variables. The chi-square test for the results in Table 1 show that the test statistic is 190.49 and the p-value for the test statistic is 0.0001, indicating a clear difference in obesity prevalence by gender. Therefore, in this study, we want to develop regression models that are independent of gender.

We also looked at the obesity prevalence by age. Table 2 shows the prevalence of obesity by age for men. The chi-square test for the results in Table 2 show that the test statistic is 86.28 and the p-value for the test statistic is 0.0001, indicating that age-specific obesity prevalence is evident. In other words, at age 19 and in their 20s and 30s, the rate of normal and obesity stage 2 is high; for those in their 40s and 50s, the rate of normal is low and the rate of obesity Stage 1 is high, and for those 60 years old or older, the rates of obesity stage 2 and stage 3 are low. Therefore, it shows that men in their 40s and 50s have a high rate of obesity.

In the same way, Table 3 shows the prevalence of obesity by age for the female population, the test statistic for the chi-square test is 284.95, and the p-value is 0.0001, indicating that women also have clear age-specific obesity prevalence. In other words, those of age 19 and in their 20s and 30s, have a very high proportion of low-weight and normal; those in their 40s and 50s have a high proportion of normal and pre-obesity stage; and those 60 years old or older have a high proportion of pre-obesity stage and obesity stage 1. Therefore, as women get older, the proportion of obesity gradually increases.

Table 2. Prevalence of obesity by age (Male)

Obesity / Age	Underweight	Normal	Pre-obesity	Obesity stage 1	Obesity stage 2	Obesity stage 3	Total
19yr,20s-30s	22	252	164	254	67	15	774
(%)	2.84	32.56	21.19	32.82	8.66	1.94	
40s-50s	13	265	259	395	46	5	983
(%)	1.32	26.96	26.35	40.18	4.68	0.51	
60s over	16	332	273	313	28		962
(%)	1.66	34.51	28.38	32.54	2.91		
total	51	849	696	962	141	20	2718
(%)	1.88	31.22	25.60	35.38	5.19	0.74	

Table 3. Prevalence of obesity by age (Female)

Obesity / Age	Underweight	Normal	Pre-obesity	Obesity stage 1	Obesity stage 2	Obesity stage 3	Total
19yr, 20s-30s	94	504	110	125	35	8	876
(%)	10.73	57.53	12.56	14.27	4.00	0.91	
40s-50s	47	632	303	301	52	9	1344
(%)	3.5	47.02	22.54	22.4	3.87	0.67	
60s over	23	415	304	413	68	8	1231
(%)	1.87	33.71	24.7	33.65	5.52	0.65	
total	164	1551	717	839	155	25	3451
(%)	4.75	44.94	20.78	24.31	4.49	0.72	

According to the above results, the prevalence of obesity in the population varies by gender and age. Therefore, it would be reasonable to develop a regression model that is independent of gender and age.

2.3. Comparative analysis of subjective body type recognition by obesity prevalence

Table 4 shows the prevalence of obesity by subjective body recognition in adult males. In the case of underweight, about 90% recognize themselves as very thin or thin, and in the case of normal, about 48% recognize themselves as normal, the highest, but about 49% recognize themselves as very thin or thin. In the case of pre-obese, the rate of recognition as normal is the highest at about 68%, and in the case of obesity stage 2 and 3, most of them recognize themselves as very obese.

TABLE 4. Subjective body type recognition by obesity prevalence(Male)

Recognition / Obesity	Very thin	Thin	Normal	Obesity	Very obesity	Total
Underweight	34	12	5			51
(%)	66.67	23.53	9.80			
Normal	77	336	409	21	2	845
(%)	9.11	33.76	48.40	2.49	0.24	
Pre-obesity	3	34	466	181	5	689
(%)	0.44	4.93	67.63	26.27	0.73	
Obesity stage 1		15	206	646	89	956
(%)		1.57	21.55	67.57	9.31	
Obesity stage 2				52	88	140
(%)				47.14	62.86	
Obesity stage 3				2	18	20
(%)				10.00	90.00	
Total	114	397	1,086	902	202	2,701

TABLE 5. Subjective body type recognition by obesity prevalence(Female)

Recognition / Obesity	Very thin	Thin	Normal	Obesity	Very obesity	Total
Underweight	39	81	42	1		163
(%)	23.93	49.69	25.77	0.61		
Normal	52	200	1,002	280	6	1,540
(%)	3.38	12.99	65.06	18.18	0.39	
Pre-obesity	10	18	246	405	32	711
(%)	1.41	2.53	34.60	56.96	4.50	
Obesity stage 1	2	18	112	495	210	830
(%)	0.24	1.33	13.49	59.64	25.30	
Obesity stage 2	2		5	44	104	155
(%)	1.29		3.23	28.39	67.10	
Obesity stage 3				1	23	24
(%)				4.17	95.83	
total	105	310	1,407	1,226	375	3,423

Table 5 shows the subjective body recognition of obesity prevalence in women. In underweight cases, about 74% of the respondents perceived themselves to be very thin or thin, while 26% recognized themselves as normal. In normal cases, the rate of recognition as normal is the highest at about 65%, but the rate of recognition as obese is also about 18%. In the case of pre-obesity, about 57% recognize themselves as obese, but about 35% recognize themselves as normal. In the case of obesity stages 1, 2, and 3, most of the women recognize themselves as obese or very obese

In the subjective body type recognition of obesity prevalence by gender, males tend to recognize weight as lower than the result of obesity prevalence, while females tend to recognize weight as higher than the result of obesity prevalence.

3. Obesity Regression Model

3.1. 1st Variable Selection(Correlation Analysis)

We determined the correlation coefficient between BMI and blood test data variables as the primary variable selection criterion. We compared the differences between men and women by age with BMI and blood test variables that are of low significance.

We selected the primary variable based on the correlation coefficient between the BMI and the blood test explanatory variables. For those of age 19 and in their 20s and 30s, hepatitis B surface antigen, hepatitis C antibodies, BUN and blood creatinine were less significant for both men and women, while hemoglobin was less significant for women (Table 6). Therefore, twelve blood factors were selected in the primary variable selection for men, and eleven blood factors were selected for women, but not all were the same factors. On the other hand, in those in their 40s and 50s, hepatitis B surface antigens and hepatitis C antibodies were less significant for both men and women, total cholesterol and platelets were less significant for men, and blood urea nitrogen and creatinine were less significant for women(Table 7).

For those 60 years old and older, total cholesterol, hepatitis B surface antigens and hepatitis C antibodies, blood urea nitrogen and platelets were less significant for both men and women, while AST(SGOT), blood creatinine, white blood cell and uric acid were additionally less significant for men(Table 8). Therefore, seven blood factors were selected in the primary variable selection for men, and eleven blood factors were selected for women. Hepatitis B surface antigens and hepatitis C antibodies were less significant for men and women of all ages, and for women of all ages, and additionally, blood urea nitrogen was less significant for women of all ages. Consequently, the correlation coefficients of BMI and blood test variables were clearly different by age and gender.

TABLE 6. Correlation between BMI and blood test data variables (19yr, $20s \sim 30s$)

		Male			Female		
Variable	Label	Correlation coefficient	p-Value	Choice	Correlation coefficient	p-Value	Choice
HE_{glu}	Fasting blood glucose	0.33699	$< .0001$	◯	0.33845	$< .0001$	◯
HE_{HbA1c}	Glycated hemoglobin	0.39271	$< .0001$	◯	0.35208	$< .0001$	◯
HE_{chol}	Total cholesterol	0.26764	$< .0001$	◯	0.18405	$< .0001$	◯
HE_{TG}	Triglycerides	0.28500	$< .0001$	◯	0.35352	$< .0001$	◯
HE_{HBsAg}	Hepatitis B surface antigen	0.03934	0.2781	×	0.02990	0.3857	×
HE_{ast}	AST(SGOT)	0.38319	$< .0001$	◯	0.18129	$< .0001$	◯
HE_{alt}	ALT(SGPT)	0.46760	$< .0001$	◯	0.29614	$< .0001$	◯
HE_{hcv}	Hepatitis C Virus antibody	-0.04087	0.2589	×	-0.04916	0.1529	×
HE_{HB}	Hemoglobin	0.13743	0.0001	◯	0.07103	0.0386	×
HE_{HCT}	Hematocrit HT	0.15259	$< .0001$	◯	0.10789	0.0017	◯
HE_{BUN}	Blood Urea Nitrogen	0.03750	0.3002	×	0.02115	0.5387	×
HE_{crea}	Serum creatinine	0.04838	0.1813	×	-0.00582	0.8657	×
HE_{WBC}	White blood cell	0.31469	$< .0001$	◯	0.27530	$< .0001$	◯
HE_{RBC}	Red blood cell	0.18826	$< .0001$	◯	0.21928	$< .0001$	◯
HE_{Bplt}	Platelet	0.10996	0.0023	◯	0.20837	$< .0001$	◯
HE_{Uacid}	Uric acid	0.30424	$< .0001$	◯	0.34962	$< .0001$	◯

3.2. 2nd Variable Selection(stepwise variable selection)

We used the stepwise variable selection method to select secondary variables for the primary significance variables selected by correlation analysis. In the stepwise variable selection method, we selected significant variables by conducting a partial F-test at a significance level of 0.15 while maximizing the coefficient of determination, and chose the number of explanatory variables p

TABLE 7. Correlation between BMI and blood test data variables ($40s \sim 50s$)

		Male			Female		
Variable	Label	Correlation coefficient	p-Value	Choice	Correlation coefficient	p-Value	Choice
HE_{glu}	Fasting blood glucose	0.11755	0.0003	◯	0.2385	< .0001	◯
HE_{HbA1c}	Glycated hemoglobin	0.12595	< .0001	◯	0.19758	< .0001	◯
HE_{chol}	Total cholesterol	0.05861	0.0692	×	0.10107	0.0003	◯
HE_{TG}	Triglycerides	0.21541	< .0001	◯	0.23145	< .0001	◯
HE_{HBsAg}	Hepatitis B surface antigen	-0.04158	0.1983	×	0.01253	0.6508	×
HE_{ast}	AST(SGOT)	0.12796	< .0001	◯	0.10393	0.0002	◯
HE_{alt}	ALT(SGPT)	0.30934	< .0001	◯	0.29148	< .0001	◯
HE_{hcv}	Hepatitis C Virus antibody	−0.00616	0.8487	×	0.01523	0.5822	×
HE_{HB}	Hemoglobin	0.20891	< .0001	◯	0.12916	< .0001	◯
HE_{HCT}	Hematocrit HT	0.19453	< .0001	◯	0.14139	< .0001	◯
HE_{BUN}	Blood Urea Nitrogen	0.09533	0.0031	◯	0.0027	0.9223	×
HE_{crea}	Serum creatinine	0.11154	0.0005	◯	−0.00046	0.9866	×
HE_{WBC}	White blood cell	0.13361	< .0001	◯	0.25796	< .0001	◯
HE_{RBC}	Red blood cell	0.21784	< .0001	◯	0.20534	< .0001	◯
HE_{Bplt}	Platelet	0.03865	0.2310	×	0.18556	< .0001	◯
HE_{Uacid}	Uric acid	0.21797	< .0001	◯	0.26804	< .0001	◯

to be less than or equal to the following Mallow's $C(p)$:

$$C(p) = \frac{SSE_p}{MSE} - (n - 2p),$$

where n is the sample size, MSE is the residual mean square after regression on the complete set of explanatory variables, and SSE_p is the error sum of squares for the model with p explanatory variables.

Table 10 shows the explanatory variables by gender and age that were selected by the above method.

TABLE 8. Correlation between BMI and blood test data variables (over 60 years old)

		Male			Female		
Variable	Label	Correlation coefficient	p-Value	Choice	Correlation coefficient	p-Value	Choice
HE_{glu}	Fasting blood glucose	0.19223	$< .0001$	◯	0.17802	$< .0001$	◯
HE_{HbA1c}	Glycated hemoglobin	0.20947	$< .0001$	◯	0.1928	$< .0001$	◯
HE_{chol}	total cholesterol	-0.00921	0.7814	×	-0.05238	0.0746	×
HE_{TG}	Triglyceride	0.16755	$< .0001$	◯	0.14632	$< .0001$	◯
HE_{HBsAg}	Hepatitis B surface antigen	0.00888	0.7894	×	0.02152	0.4642	×
HE_{ast}	AST(SGOT)	0.05992	0.0708	×	0.161	$< .0001$	◯
HE_{alt}	ALT(SGPT)	0.18555	$< .0001$	◯	0.25448	$< .0001$	◯
HE_{hcv}	Hepatitis C Virus antibody	0.00542	0.8703	×	-0.07039	0.0165	×
HE_{HB}	Hemoglobin	0.19627	$< .0001$	◯	0.14177	$< .0001$	◯
HE_{HCT}	Hematocrit HT	0.1552	$< .0001$	◯	0.13059	$< .0001$	◯
HE_{BUN}	Blood Urea Nitrogen	-0.02664	0.4221	×	0.03774	0.2028	×
HE_{crea}	Serum creatinine	0.07504	0.0236	×	0.10527	0.0003	◯
HE_{WBC}	White blood cell	0.03678	0.2680	×	0.10926	0.0002	◯
HE_{RBC}	Red blood cell	0.15967	$< .0001$	◯	0.15798	$< .0001$	◯
HE_{Bplt}	Platelet	-0.05501	0.0974	×	0.03205	0.2767	×
HE_{Uacid}	Uric acid	0.08088	0.0147	×	0.22173	$< .0001$	◯

3.3. Remove Outliers or Influential Observations

We removed outliers or influential observations based on standardized residuals and Cook's distance statistics for the regression model of significant explanatory variables selected by the above stepwise variable selection method.

The following studentized residual, the r_i for the i-th dependent variable y_i was removed as an outlier if it was greater than the absolute value of ± 2,

$$r_i = \frac{y_i - \hat{y}_{(i)}}{MSE_{(i)}/(1 - h_{(ii)})},$$

TABLE 9. Selection variables by step-by-step

Age		Variable Entered	Number of variables	$C(p)$	R^2
19yr, $20s \sim 30$	Male	HE_{alt}, HE_{HbA1c}, HE_{Uacid}, HE_{WBC} HE_{glu}, HE_{TG}, HE_{RBC}, HE_{chol}	8	6.2568	0.3720
	Female	HE_{TG}, HE_{Uacid}, HE_{HbA1c}, HE_{WBC}, HE_{alt}, HE_{glu}, HE_{Bplt}, HE_{ast}	8	14.7458	0.3319
$40 \sim 50$	Male	HE_{alt}, HE_{WBC}, HE_{Uacid}, HE_{HbA1c}, HE_{TG}, HE_{RBC}	6	3.6000	0.1804
	Female	HE_{alt}, HE_{WBC}, HE_{Uacid},HE_{glu}, HE_{Bplt},,HE_{RBC}, HE_{TG}	7	7.0984	0.2065
$60s$ over	Male	HE_{HbA1c}, HE_{HB}, HE_{alt}, HE_{Uacid}, HE_{TG}, HE_{Bplt}	6	4.9377	0.1168
	Female	HE_{alt}, HE_{Uacid}, HE_{glu}, HE_{RBC}, HE_{TG}, HE_{HbA1c}	6	8.6158	0.1376

where, $\hat{y}_{(i)}$ and $MSE_{(i)}$ were the predicted value for the i-th observation and the mean square error, based on the estimated model with the i-th observation deleted, respectively, and $h_{(ii)}$ was the leverage for the i-th observation.

We also removed the i-th observation if the following Cook's distance statistics D_i is greater than $4/n$:

$$D_i = \frac{\Sigma_{j=1}^{n}(\hat{y}_{i(F)} - \hat{y}_{j(i)})^2}{(p+1)MSE},$$

where, $\hat{y}_{i(F)}$ is the predicted response value and the mean squared error of the model obtained by the whole sample, respectively, and $\hat{y}_{j(i)}$ is the predicted response value of the model obtained when excluding the i-th observation.

3.4. Final Model

For the regression models estimated using samples that removed outliers or influential observations by the above method, we derived the final model by excluding explanatory variables whose estimates of regression coefficients were not significant, or whose sign of regression coefficients did not match those of the correlation coefficients. We also conducted multicollinearity diagnosis using the variance inflation factor(VIF) for the final regression model.

3.4.1. *Age: aged 19, in their 20s and 30s.* The final model for men aged 19, in their 20s and 30s has the coefficient of determination(R^2), 0.5148 and the final model does not have multicollinearity because the VIFs of each descriptive variable all have a value near 1. Comparing the importance of each explanatory variable in the final model based on the standardized estimate of regression

TABLE 10. Final model for men aged 19, in their 20s and 30s

Variable	Label	Parameter estimate	Standard error	t Value	$Pr > \|t\|$	Standardized estimate	Variance inflation
Intercept	Intercept	7.86186	1.02872	7.64	< .0001	0	0
HE_{Uacid}	Uric acid	0.47685	0.0727	6.56	< .0001	0.1882	1.10968
HE_{WBC}	White blood cell	0.27788	0.05593	4.97	< .0001	0.14223	1.10444
HE_{TG}	Triglyceride	0.00333	0.00123	2.72	0.0068	0.0823	1.23637
HE_{alt}	ALT(SGPT)	0.06283	0.00511	12.3	< .0001	0.38288	1.30681
HE_{glu}	Fasting blood sugar	0.08136	0.009	9.04	< .0001	0.2572	1.09051
HE_{chol}	Total Cholesterol	0.00939	0.00272	3.45	0.0006	0.10411	1.22487

TABLE 11. ANOVA Table for men in their 19yr, 20s and 30s

Source	DF	Sum of squares	Mean squares	F Value	$Pr > F$
Model	6	3376.851	562.8085	115.66	< .0001
Error	654	3182.4	4.866605		
Corrected total	660	6559.251			

coefficients, ALT(SGPT) and fasting blood glucose have a significant effect on obesity, but triglycerides do not(Table 10).

The final model for women aged 19 and in their 20s and 30s has a determination coefficient of 0.4128 and does not have multicollinearity. In the final regression model, although it affects obesity in the order of triglycerides, uric acids, and glycolytic hemoglobin, platelets do not have a significant effect on obesity(Table 12).

3.4.2. *Age: 40s and 50s.* The final model for men in their 40s and 50s has a determination coefficient of 0.3265 and does not have multicollinearity. In the final model, ALT(SGPT) and uric acid have the greatest effects on obesity, but triglyceride and white blood cells have no significant effect on obesity(Table 14). The final model for women in their 40s and 50s has a determination coefficient of 0.3786. Explanatory variables within the final model do not have multicollinearity, and affect obesity in the order of fasting blood sugar, ALT(SGPT), and uric acid, but white blood cells and red blood cells do not have a significant effect on obesity(Table 16).

Meanwhile the final model for women in their 40s and 50s has the coefficient of determination(R^2) 0.3786 as shown in Table 13 below. The variance inflation

TABLE 12. Final model for women aged 19, in their 20s and 30s

Variable	Label	Parameter estimate	Standard error	t Value	$Pr > \|t\|$	Standardized estimate	Variance inflation
Intercept	Intercept	0.72426	1.02872	7.64	$< .0001$	0	0
HE_{TG}	Triglyceride	0.01256	0.00178	7.07	$< .0001$	0.23093	1.28473
HE_{Uacid}	Uric Acid	0.61037	0.09012	6.77	$< .0001$	0.2074	1.1292
HE_{HbA1c}	Hemoglobin, HbA1c	1.6877	0.28289	5.97	$< .0001$	0.1958	1.29682
HE_{WBC}	White blood cell	0.19095	0.05369	3.56	$< .0004$	0.10991	1.14972
HE_{alt}	ALT(SGPT)	0.05337	0.0105	5.08	$< .0001$	0.15382	1.10301
HE_{glu}	Fasting blood sugar	0.05914	0.01064	5.56	< 0001	0.18709	1.36415
HE_{Bplt}	Platelet	0.00349	0.00132	2.64	0.0085	0.08056	1.12303

TABLE 13. ANOVA Table for women aged 19, in their 20s and 30s

Source	DF	Sum of Squares	Mean Squares	F Value	$Pr > F$
Model	7	1976.145	282.3065	71	$< .0001$
Error	707	2810.97	3.97591		
Corrected Total	714	4787.115			

TABLE 14. Final model for men in their 40s and 50s

Variable	Label	Parameter estimate	Standard error	t Value	$Pr > \|t\|$	Standardized estimate	Variance inflation
Intercept	Intercept	11.36908	1.15509	9.84	$< .0001$	0	0
HE_{alt}	ALT(SGPT)	0.05003	0.00496	10.09	$< .0001$	0.31087	1.15532
HE_{RBC}	Red blood cell	0.78747	0.19243	4.09	$< .0001$	0.12135	1.07077
HE_{Uacid}	Uric acid	0.56203	0.06252	8.99	$< .0001$	0.27598	1.14772
HE_{HbAlc}	Glycated hemoglobin	0.67744	0.11637	5.82	$< .0001$	0.17672	1.1219
HE_{TG}	Triglyceride	0.000963	0.000577	1.67	0.0955	0.05224	1.19305
HE_{WBC}	White blood cell	0.08822	0.04211	2.09	0.0369	0.06298	1.10062

Table 15. ANOVA Table for men in their 40s and 50s

Source	DF	Sum of squares	Mean squares	F Value	$Pr > F$
Model	6	1668.45	278.075	66.26	$< .0001$
Error	820	3441.366	4.19679		
Corrected total	826	5109.816			

Table 16. Final model for women in their 40s and 50s

Variable	Label	Parameter estimate	Standard error	t Value	$Pr > \|t\|$	Standardized estimate	Variance inflation
Intercept	Intercept	9.63217	0.90116	10.69	$< .0001$	0	0
HE_{alt}	ALT(SGPT)	0.05389	0.00664	8.11	$< .0001$	0.20796	1.15219
HE_{WBC}	White blood cell	0.1201	0.0454	2.65	0.0083	0.0688	1.18629
HE_{Uacid}	Uric acid	0.58082	0.07064	8.22	$< .0001$	0.20731	1.11511
HE_{glu}	Triglyceride	0.04345	0.00484	8.97	$< .0001$	0.22786	1.13103
HE_{Bplt}	Platelet	0.00483	0.00483	5.14	$< .0001$	0.12969	1.11689
HE_{RBC}	Red blood cell	0.67199	0.19253	3.49	$< .0001$	0.08727	1.09669
HE_{TG}	Triglyceride	0.00735	0.00103	7.16	< 0001	0.18500	1.17091

Table 17. ANOVA Table for women in their 40s and 50s

Source	DF	Sum of squares	Mean squares	F Value	$Pr > F$
Model	7	2590.186	370.0265	94.87	$< .0001$
Error	1090	4251.263	3.90024		
Corrected total	1097	6841.449			

factors of each variable show values around 1, and there is no multicollinearity. Based on the standardized regression coefficient estimate, in the case of women in their 40s and 50s, it was found that fasting blood sugar, ALT(SGPT), and uric acid had a significant effect on obesity, while white blood cells and red blood cells did not significantly affect obesity.

3.4.3. *Age:60 years old and older.* The final model for men 60 years old and older has a determination coefficient of 0.2356. Explanatory variables within the final model affect obesity in the order of ALT(SGPT), glycated hemoglobin, uric acid, and triglycerides in the absence of multicollinearity(Table 18).

Table 18. Final model for men 60 years old and older.

Variable	Label	Parameter estimate	Standard error	t Value	$Pr > \|t\|$	Standardized estimate	Variance inflation
Intercept	Intercept	12.30624	1.08277	11.37	$< .0001$	0	0
HE_{HbAlc}	Glycated hemoglobin	0.57349	0.0908	6.32	$< .0001$	0.20637	1.06567
HE_{HB}	Hemoglobin	0.32354	0.05674	5.7	$< .0001$	0.19593	1.17869
HE_{alt}	ALT(SGPT)	0.05095	0.00714	7.14	$< .0001$	0.31087	1.15532
HE_{Uacid}	Uric acid	0.32418	0.06252	8.99	$< .0001$	0.24002	1.12947
HE_{TG}	Triglyceride	0.00318	0.00103	3.09	0.0021	0.10363	1.12422

Table 19. ANOVA Table for men 60 years old and older.

Source	DF	Sum of squares	Mean squares	F Value	$Pr > F$
Model	5	897.0784	179.4157	47.03	$< .0001$
Error	763	2910.964	3.81516		
Corrected total	768	3808.043			

Table 20. Final model for women over 60 years old.

Variable	Label	Parameter estimate	Standard error	t Value	$Pr > \|t\|$	Standardized estimate	Variance inflation
Intercept	Intercept	14.53567	1.11565	13.03	$< .0001$	0	0
HE_{HbAlc}	Glycated hemoglobin	0.46192	0.10971	4.21	$< .0001$	0.1213	1.07374
HE_{HB}	Hemoglobin	0.1726	0.0676	2.65	0.0108	0.07338	1.06864
HE_{alt}	ALT(SGPT)	0.06652	0.00792	8.4	$< .0001$	0.20796	1.15219
HE_{Uacid}	Uric acid	0.58328	0.07064	8.79	$< .0001$	0.25054	1.04977
HE_{TG}	Triglyceride	0.00493	0.00117	4.22	< 0001	0.12201	1.08139

The final model for women 60 years old and older has a determination coefficient of 0.2308. Explanatory variables within the final model do not have multicollinearity, and while uric acid and ALT (SGPT) have a significant effect on obesity, hemoglobin does not(Table 20).

Table 21. ANOVA Table for women over 60 years old.

Source	DF	Sum of squares	Mean squares	F Value	$Pr > F$
Model	5	2590.186	303.0681	59.72	$< .0001$
Error	995	5049.239	5.07461		
Corrected total	1000	6564.58			

4. Results and Discussion

In this study, we used the blood test data as explanatory variables in the regression model to predict BMI, and developed independent regression models for gender and age because there are obvious differences between gender and age in obesity prevalence. The primary variables were selected by correction between BMI and variables, and the secondary variables were selected by determination coefficient in stepwise method, and the $6 \sim 8$ explanatory variables out of sixteen were selected. In the final model, we consider comparing the characteristics of the key blood test explanatory variables, as well as the predictive power of the model according to gender and age group(Table 22).

The explanatory variables presented in Table 22 are listed in order of importance that affects obesity, based on estimates of the standardized coefficients of the final model. In the case of of those aged 19, in their 20s and 30s, the ALT(SGPT) and fasting blood glucose of men have a significant associate with obesity, but triglycerides do not. For women, triglycerides, uric acids, and glycolytic hemoglobin of affects obesity in that order, while platelets do not have a significant associate with obesity.

In the case of those in their 40s and 50s, the ALT (SGPT) and uric acid of men have the greatest associate with obesity, but triglyceride and white blood cells have no significant associate with obesity. For women, fasting blood sugar, ALT (SGPT), and uric acid affect obesity in that order, but white blood cells and red blood cells do not have a significant association with obesity.

In the case of those 60 years old and older, both the uric acid and ALT (SGPT) of women have a significant associate with obesity, while hemoglobin does not. For men, ALT (SGPT), glycated hemoglobin, uric acid, and triglycerides affect obesity in that order.

In terms of gender, triglycerides, uric acid, and ALT(SGPT) were associated in common with a BMI in all age groups for women, whereas, in the case of men, ALT (SGPT) and uric acid were commonly associated with all age groups. The predictive power of obesity in the regression model is the highest for both men and women aged 19, in their 20s and 30s by blood data, and the predictive power decreases with increasing age.

Although the key explanatory variables in the final regression model differ somewhat in terms of composition and order of importance, the final model also

showed that ALT (SGPT) is the most important explanatory variable affecting obesity for men of all ages. However, in the final model of women, ALT (SGPT) is not the most influential variable for obesity, but it is a significant variable that affects obesity in all age groups of women, along with triglycerides and uric acids.

Comparison of our research results with the literature shows that our findings are consistent with the cited research results and known results. ALT (SGPT) is known to be associated with obesity [4], [35], [36], [41]. ALT(SGPT) has been reported to be higher in men than in women, but it is not yet known whether these results are due to the effects of sex hormones or other mechanisms [35], [36], but they are associated with body lean mass and are known to affect obesity in men [7]. As an empirical study, studies of the Korean population showed a higher risk of ALT increasing as a result of increased BMI [29] and studies of Americans reported a positive correlation between ALT and BMI.

Also, uric acid(UA) is an essential risk factor of obesity, which may result in increased incidence of metabolic syndrome [12]. It has been confirmed that SUA is independently and positively correlated with the risk of obesity [13], [43], [45]. In this study, Uric acid(UA) is the most important explanatory variable that is associated with obesity for both men and women of all ages.

In our results, triglycerides was associated with obesity in women regardless of age. Joshi et al.[25] found a statistical significant correlation between BMI and triglycerides [47]. Among nondiabetic obese adults, serum TG level was positively associated with visceral fat area [20].

In our analysis, the fasting blood glucose, glycated hemoglobin, Hemoglobin, WBC, and RBC are associated with obesity and they are consistent with the research works. Both obese male and female persons showed higher levels of fasting serum glucose and glycosylated hemoglobin [14]. Hemoglobin concentration is significantly increased in both male and female obese persons [3]. Obesity associated with increased red blood cell, and RBC folate increased incrementally with BMI [24]. Pratley et al. [37] indicates that age, race, and obesity are significantly associated with the WBC count in healthy individuals.

The blood data of association with obesity in the final model are $6 \sim 8$ factors that differ somewhat depending on age and gender. Previous reports described positive associations between BMI or obesity and several blood factors [2]-[8], but little analysis has investigated the general population for the relationship between BMI and all blood test data included in KNHANES based on age and gender.

Our analysis provides for the first time the estimates of the relation of interaction between BMI and all of the blood test data included in KNHANES based on age and gender. The regression analysis has revealed a statistically significant effect of age on six to eight blood data and BMI relation in both males and females.

TABLE 22. The major explanatory variables and predictive power of models according to gender and age group

Age	Gender	Explanatory Variables (arrange in order of importance)	R^2
19yr,$20 \sim 30$	Male	ALT(SGPT), Fasting blood glucose, Uric acid, WBC	0.5148
	Female	Triglyceride, Uric acid, Glycated hemoglobin, Fasting blood glucose, ALT(SGPT)	0.4128
$40 \sim 50$	Male	ALT(SGPT), Uric acid, Glycated hemoglobin, RBC	0.3265
	Female	Fasting blood glucose, ALT(SGPT), Uric acid, Triglyceride, Platelet	0.3786
$60s$ over	Male	ALT(SGPT), Glycated hemoglobin, Hemoglobin, Uric acid	0.2356
	Female	Uric acid, ALT(SGPT), Triglyceride, Glycated hemoglobin	0.2308

The contribution of this study is to use blood data in addition to BMI in diagnosing obesity for young adults so that a more accurate diagnosis or prediction can be made. However, while in the present findings, we have strengths for young adults, we also have limitations, in that the predictive power is low for older people.

Because the body composition changes with age and time, it is necessary to adjust the BMI threshold according to age as mentioned by [34]. Therefore, for the young adult generation, this study could be utilized in obesity prediction as a complement to BMI.

5. Conclusion

In the group of age 19, 20s and 30s group, this analysis presents the predictive power of obesity for men was about 52%, which was higher than that for women, 41%. The coefficient of determination that represents the predictive power of the regression model is the highest for both men and women of age 19, in their 20s and 30s, and the predictive power decreases with increasing age. Therefore, for older people, it is reasonable to predict obesity by considering other methods.

References

[1] Arif AA, Rohrer JE., Patterns of alcohol drinking and its association with obesity: data from the third national health and nutrition examination survey, $1988 - 1994$. BMC Public Health (2005);5(1) : 126.

[2] R Akter, A Nessa, M F Husain, F Wahed, N Khatun, M Yesmin, S Nasreen, T Tajkia, Effect of Obesity on Fasting Blood Sugar, Mymensingh Med J. (2017) Jan;26(1) : $7 - 11$.

[3] R Akter, A Nessa, D Sarker, M Yesmin, Effect of Obesity on Hemoglobin Concentration, Mymensingh Med J. (2017) Apr;26(2) : 230 − 234.

[4] Adams L. A., Knuiman M. W., Divitini M. L., Olynyk J. K., Body mass index is a stronger predictor of alanine aminotransaminase levels than alcohol consumption. Journal of Gastroenterology and Hepatology. (2008);23, 7, Part 1:1089 − 1093.

[5] R. Barazzoni, Gianluca Gortan Cappellari, Annamaria Semolic, Enrico Chendi, Mario Ius, Roberta Situlin, Michela Zanetti, Pierandrea Vinci, and Gianfranco Guarnieri, The Association between Hematological Parameters and Insulin Resistance Is Modified by Body Mass Index – Results from the North-East Italy MoMa Population Study, PLoS One. (2014); 9(7): e101590.

[6] G Banfi and M Del Fabbro, Relation between serum creatinine and body mass index in elite athletes of different sport disciplines, Br J Sports Med. (2006) Aug; 40(8) : 675−678.

[7] Bekkelund, Svein Ivar, and Rolf Jorde. "Alanine Aminotransferase and Body Composition in Obese Men and Women." Disease markers vol. 2019 1695874. 26 Aug. (2019), doi:10.1155/2019/1695874

[8] Yuan-Lung Cheng et al., Inverse Association between Hepatitis B Virus Infection and Fatty Liver Disease: A Large-Scale Study in Populations Seeking for Check-Up, PLOS ONE, August (2013), Vol. 8(8).

[9] Cohen S, Janicki-Deverts D. Who's stressed? Distributions of psychological stress in the United States in probability samples from 1983, 2006, and 2009. J Appl Soc Psychol.(2012);42 : 1320 − 1334.

[10] Consultation WHOE, Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. Lancet (2004) 363, 157 − 163 .

[11] Clarice D. Brown, Millicent Higgins, Karen A. Donato, Frederick C. Rohde, Robert Garrison, Eva Obarzanek, Nancy D. Ernst, and Michael Horan, Body Mass Index and the Prevalence of Hypertension and Dyslipidemia, Obesity Research,(2012) https://doi.org/10.1038/oby.2000.79, 06 September.

[12] Chang JB, Chen YL, Hung YJ, et al. The role of uric acid for predicting future metabolic syndrome and type 2 diabetes in older people. J Nutr Health Aging. (2017);21(3) : 329 − 335.

[13] Chu FY, Chang CC, Huang PH, et al. The association of uric acid calculi with obesity, prediabetes, type 2 diabetes mellitus, and hypertension. Biomed Res Int. (2017);2017 : 1 − 6.

[14] R. K. Das, A Nessa, M A Hossain, N I Siddiqui, M A Hussain, Fasting serum glucose and glycosylated hemoglobin level in obesity, Mymensingh Med J. (2014) Apr;23(2) : 221−8.

[15] Dorit Samocha-Bonet, Dan Justo, Ori Rogowski, Nili Saar, Subchi Abu-Abeid, Galina Shenkerman, Itzhak Shapira, Shlomo Berliner, Aaron Tomer, Platelet counts and platelet activation markers in obese subjects, Mediators Inflamm. (2008); 834153. doi: 10.1155/2008/834153.

[16] Eline S. van der Valk,1,2 Mesut Savas,1,2 and Elisabeth F. C. van Rossum, Stress and Obesity: Are There More Susceptible Individuals?, Curr Obes Rep. (2018); 7(2) : 193 − 203.

[17] Eknoyan, G. Adolphe Quetelet (1796 − 1874) The average man and indices of obesity. Nephrol. Dial. Transplant.(2008); 23, 47 − 51

[18] Heymsfield, S. B. et al., Scaling of adult body weight to height across sex and race/ethnic groups: relevance to BMI. Am. J. Clin. Nutr.(2014) 100, 1455 − 1461.

[19] M.A. Hammad, S.A. Syed Sulaiman, N.A. Aziz, T.M. Elsayed, D.A. Mohamed Noor, PSY7-Impact of obesity on glycated heloglobin control among patients with type 2 diabets mellitus, Valuein health, Open ArchiveDOI: https://doi.org/10.1016/j.jval.(2018).09.2584.

[20] Huang, Chiao-Yu,Huang, Hsien-Liang, Yang, Kuen-Cheh, Lee, Long-Teng, Yang, Wei-Shiung, Huang, Kuo-Chin, Tseng, Fen-Yu, Serum Triglyceride Levels Independently

Contribute to the Estimation of Visceral Fat Amount Among Nondiabetic Obese Adults, Medicine: June (2015), Vol. 94(23), pe965.

[21] Jae Ho Jang, Hong Joo Kim et al., Comparison of the prevalence of insulin resistance between the HCV Antibody positive and non-infected examinee, The Korean Journal of Medicine: (2010),Vol. 79(4).

[22] Mei-Chu Yen Jean, Chia-Chang Hsu, Teng-Hung Yu et al., Association between lifestyle and hematological parameters: A study of Chinese male steelworkers, J. Clin Lab Anal. (2019);33:e22946.

[23] Johanna C. Purdy, Joseph J Shatzel, The hematologic consequences of obesity, Eur J Haematol. (2021) Mar;106(3) : 30 − 319.

[24] Julia K. Bird, Alayne G Ronnenberg, Sang-Woon Choi, Fangling Du, Joel B Mason, Zhenhua Liu, Obesity is associated with increased red blood cell folate despite lower dietary intakes and serum concentrations, J Nutr. (2015) Jan;145(1) : 79 − 86.

[25] S. Joshi, A. pranita, J. kharche, G. Godbole, Correlation of body mass index & triglyceride levels in middle aged women, (2018) Vol. 275, E227, August 01.

[26] King GA, Fitzhugh E, Bassett Jr D, et al., Relationship of leisure-time physical activity and occupational activity to the prevalence of obesity. International journal of obesity and related metabolic disorders: journal of the International Association for the Study of Obesity (2001);25(5) : 606.

[27] Knutson KL, Van Cauter E, Rathouz PJ, DeLeire T, Lauderdale DS. Trends in the prevalence of short sleepers in the USA: 1975 − 2006. Sleep. (2010);33(1) : 37 − 45.

[28] Kleiner D. E., Brunt E. M., van Natta M., et al. Design and validation of a histological scoring system for nonalcoholic fatty liver disease. Hepatology. (2005);41(6) : 1313−1321.

[29] Kim J., Jo I. Relationship between body mass index and alanine aminotransferase concentration in non-diabetic Korean adults. European Journal of Clinical Nutrition. (2010);64(2) : 169 − 175.

[30] Lemieux S, Prud'homme D, Bouchard C, et al., A single threshold value of waist girth identifies normal-weight and overweight subjects with excess visceral adipose tissue. Am J Clin Nutr (1996); 64 : 685 − 693.

[31] Giulio Marchesini, Simona Moscatiello, Silvia Di Domizio, Gabriele Forlani, Obesity-Associated Liver Disease, The Journal of Clinical Endocrinology & Metabolism, Volume 93, Issue 11, November (2008), pp $s74 - s80$.

[32] Mummery WK, Schofield GM, Steele R, et al., Occupational Sitting Time and Overweight and Obesity in Australian Workers. American Journal of Preventive Medicine 2005;29(2) : 91 − 7.

[33] Matteoni C., Younossi Z., Gramlich T., Boparai N., Liu Y., Mccullough A., Nonalcoholic fatty liver disease: a spectrum of clinical and pathological severity. Gastroenterology. (1999);116(6) : 1413 − 1419.

[34] A. M. Nevill1 and G S Metsios The need to redefine age- and gender-specific overweight and obese body mass index cutoff points, Nutr Diabetes. (2015) Nov; 5(11): e186

[35] Prati D., Taioli E., Zanella A., et al., Updated definitions of healthy ranges for serum alanine aminotransferase levels. Annals of Internal Medicine. (2002);137(1) : 1 − 10.

[36] Poustchi H., George J., Esmaili S., et al. Gender differences in healthy ranges for serum alanine aminotransferase levels in adolescence. PLoS One. (2011);6(6, article e21178)

[37] R E Pratley, C Wilson, C Bogardus, Relation of the white blood cell count to obesity and insulin resistance: effect of race and gender, Obes Res. (1995) Nov;3(6) : 563 − 71.

[38] van Rossum EF., Obesity and cortisol: new perspectives on an old theme. Obesity (Silver Spring) 2017;25(3) : 500 − 501.

[39] K.J. Rothman, BMI-related errors in the measurement of obesity, International Journal of Obesity (2008) 32, $S56 - S59$.

[40] Rabindra Nath Das, Diabetes and obesity determinants based on blood serum, conferenceseries.com, Journal of Diabetes & Metabolism Diabetes Meet (2018) Vol.9, July 30 − 31, 2018 Melbourne, Australia.
[41] Stranges S., Dorn J. M., Muti P., et al. Body fat distribution, relative weight, and liver enzyme levels: a population-based study. Hepatology. (2004);39(3) : 754 − 763.
[42] Trefethen, Nick. "New BMI (Body Mass Index)". Ox.ac.uk. Mathematical Institute, University of Oxford. Retrieved 5 February (2019).
[43] Tanaka K, Ogata S, Tanaka H, Omura K, Honda C; Osaka Twin Research Group, et al. The relationship between body mass index and uric acid: a study on Japanese adult twins. Environ Health Prev Med. (2015); 20(5) : 347 − 53.
[44] C Walton, B Lees, D Crook, M Worthington, I F Godsland, J C Stevenson, Body fat distribution, rather than overall adiposity, influences serum lipids and lipoproteins in healthy men independently of age, Am J Med. (1995) Nov;99(5):459 − 64.
[45] Wang H, Wang L, Xie R, Dai W, Gao C, Shen P, et al. Association of Serum Uric Acid with Body Mass Index: A Cross-Sectional Study from Jiangsu Province, China. Iran J Public Health. (2014); 43(11) : 1503 − 9.
[46] Yanga F, Lv JH, Lei SF, Chena XD., Receiver-operating characteristic analyses of body mass index, waist circumference and waist-to-hip ratio for obesity: Screening in young adults in central south of China. Clin Nut. (2006);25 : 1030 − 9.
[47] Yang Zou, Guotai Sheng, Meng Yu, Guobo Xie, The association between triglycerides and ectopic fat obesity: An inverted U-shaped curve, PLOS ONE, https://doi.org/10.1371/journal.pone.0243068 November 30, (2020).
[48] https://www.nhlbi.nih.gov/health/educational/lose-wt/risk.htm(accessed on at 07, May, 2021).
[49] https://www.myvmc.com/investigations/assessing-central-obesity- waist- circumference/(accessed on at 07, May, 2021).

Kwanghee Ko
Department of statistics, Chonnam National University,
Gwangju; Korea.
E-mail: kwangyeeko@naver.com

Chunyoung Oh
Department of Mathematics Education, Chonnam National University,
Gwangju, Korea.
E-mail: cyoh@jnu.ac.kr