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The Relationship between Lipid Accumulation Product, Insulin Resistance, and Obesity in Korean Adults

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Abstract

Lipid accumulation product (LAP) is a new index reflecting central lipid accumulation and is known to be a strong independent indicator for identifying the risk of cardiovascular disease (CVD) or diabetes mellitus (DM). This study was conducted to assess the relationship between the homeostasis model assessment of insulin resistance (HOMA-IR) and LAP according to the presence or absence of obesity in Korean adults. The study was carried out using data from the 2019 Korean National Health and Nutrition Examination Survey (KNHANES) and included 6,090 adults aged 20 years or older. There were several key findings. First, after adjusting for related variables, the mean of the HOMA-IR levels (M ± SE, 95% confidence interval) was positively associated with the quartiles of LAP in the overall population ($P < 0.001$), non-obese ($P < 0.001$), or obese groups ($P < 0.001$). Second, in all the groups (overall population, non-obese, and obese groups), the mean value of the fasting blood glucose ($P < 0.001$), insulin ($P < 0.001$), and the metabolic syndrome score ($P < 0.001$) increased with the increasing quartiles of LAP. Insulin resistance was thus positively associated with an increase in the LAP in Korean adults with or without obesity.

Keywords

Insulin resistance
Lipid accumulation product
Metabolic syndrome
Obese

1. Introduction

The World Health Organization (WHO) estimated in 2016 that the global obese population was 650 million people [1]. In South Korea, the obese population has increased from 35.1% in 2011 to 42.3% in 2016 [2]. Obesity is known to be a major cause of non-communicable chronic diseases

such as type 2 diabetes mellitus (T2DM), cardiovascular disease (CVD), and their complications, leading to increased morbidity and mortality rates [3]. Adipose tissue, consisting of adipocytes, pre-adipocytes, endothelial cells, fibroblasts, leukocytes, and macrophages, is known to play a significant role in metabolic regulation [4]. The lipid accumulation product (LAP) is a newly introduced obesity-related index that is calculated simply based on waist circumference (WC) and triglyceride (TG) levels [5]. In addition, LAP is known to be effective in predicting lipid accumulation in ectopic sites of the body, such as the skeletal system and pancreatic beta cells [6].

Insulin resistance is a condition in which the functionality of insulin secreted by pancreatic β-cells is impaired, leading to the inability to effectively regulate glucose homeostasis in cellular and metabolic processes. An increase in insulin resistance is known to impact the prevalence of various chronic diseases, including T2DM and metabolic syndrome (MetS) [7,8]. This condition also affects the incidence of chronic diseases such as hypertension, obesity, and dyslipidemia. Currently, research on insulin resistance in relation to obesity utilizes indices such as body mass index (BMI), WC, and the visceral adiposity index (VAI) on a global scale. However, studies on the newly introduced index, LAP, and its relationship with insulin resistance are limited. Particularly, research on LAP and insulin resistance in individuals with normal weight is scarce compared to research involving obese or diabetic patients. Therefore, this study aims to investigate the association between LAP and insulin resistance in both non-obese and obese groups among Korean adults, using data from the 2019 Korea National Health and Nutrition Examination Survey, which is the most recent data available for South Korea.

2. Materials and methods

2.1. Study participants

This study utilized data from the 8th Korea National Health and Nutrition Examination Survey conducted by the Korea Disease Control and Prevention Agency (2019). The total number of survey participants was 8,110, of which 6,542 were adults aged 20 or older. From the 6,542 individuals, 452 participants were excluded due to incomplete responses in the health questionnaire and missing results from blood pressure and blood chemistry tests. Thus, a total of 6,090 individuals were selected as the final analysis subjects. The data from the 1st year of the 8th Korea National Health and Nutrition Examination Survey was reviewed and approved by the Institutional Review Board of the Korea Disease Control and Prevention Agency (Institutional Review Board No, 2018-01-03-C-A).

2.2. Clinical characteristics and blood chemistry tests of participants

Among the participants, age was categorized as an average value, and gender was classified into male and female. Regarding lifestyle habits, individuals who consumed more than one glass of soju per week were categorized as current drinkers, and those who smoked one or more cigarettes per day were classified as current smokers. Regular exercise was defined as engaging in physical activity for 30 minutes or more per week. Body measurements included BMI, WC, systolic blood pressure (SBP), and diastolic blood pressure (DBP). Blood chemistry tests included the measurement of total cholesterol (TC), TGs, high-density lipoprotein cholesterol (HDL-C), fasting blood glucose (FBG), blood urea nitrogen (BUN), and serum creatinine (Crea). MetS was classified according to the criteria of the National Cholesterol Education Program Adult Treatment Panel III [9]. Elevated TGs were defined as TGs ≥ 150 mg/dL. Decreased HDL-C was categorized as < 50 mg/dL in women or < 40 mg/dL in men. Elevated FBG was categorized as FBG ≥ 100 mg/dL. Elevated blood pressure was defined as SBP ≥ 130 mm Hg or DBP ≥ 85 mm Hg. Abdominal obesity was defined as a WC ≥ 90 cm in men or ≥ 80 cm in women.

MetS was defined as the presence of three or more of the five components of MetS. The metabolic syndrome score (MetS score) was categorized as 0, 1, 2, 3, 4, and 5 based on the number of components present [10].

2.3. Participants' insulin resistance, obesity, and LAP

In this study, the homeostasis model assessment of insulin resistance (HOMA-IR) was calculated as follows: HOMA-IR = [fasting insulin (μU/mL) × FBG (mg/dL)] ÷ 405 [11]. Obesity was categorized as BMI ≥ 25 kg/m^2 [12]. In men, LAP was calculated as [WC (cm) - 65] × TGs (mmol/L), and in women, LAP was calculated as [WC (cm) - 58] × TGs (mmol/L) [13]. As there were no clear cutoffs for LAP in the entire population, the non-obese group, and the obese group, LAP was categorized based on quartiles.

2.4. Data analysis

Statistical analysis of the data was performed using SPSS WIN version 18.0 (SPSS Inc., Chicago, IL, USA). The distributions of participant characteristics were expressed as frequencies and percentages, while continuous data were expressed as means and standard deviations (M ± SD). The characteristics of study participants in the non-obese and obese groups were

Table 1. Clinical characteristics of research subject [*n* (%); M ± SD]

Variables	Category	Total (*n* = 6,090)	Non-obesity (*n* = 4,014)	Obesity (*n* = 2,076)	*P*-value
Age (years)		51.72 ± 16.89	51.12 ± 17.22	52.88 ± 16.18	<0.001
Gender	Male	2,714 (44.6)	1,608 (40.1)	1,106 (53.3)	<0.001
	Women	3,376 (55.4)	2,406 (59.9)	970 (46.7)	
Drinking	Current drinker	3,256 (53.5)	2,148 (53.5)	1,108 (53.4)	0.469
Smoking	Current smoker	1,060 (17.7)	660 (16.4)	400 (19.3)	0.003
Exercising	Regular exerciser	5,420 (89.0)	3,588 (89.4)	1,832 (88.2)	0.096
SBP (mmHg)		119.76 ± 16.47	117.90 ± 16.74	123.36 ± 15.33	<0.001
DBP (mmHg)		75.67 ± 9.75	74.43 ± 9.39	78.09 ± 9.98	<0.001
BMI (kg/m^2)		23.94 ± 3.59	21.93 ± 2.00	27.82 ± 2.71	<0.001
WC (cm)		84.07 ± 10.41	78.96 ± 7.58	93.95 ± 7.64	<0.001
LAP		36.06 ± 35.97	24.92 ± 23.53	57.59 ± 44.61	<0.001
TC (mg/dL)		192.74 ± 37.97	191.76 ± 36.96	194.64 ± 36.80	<0.001
TGs (mg/dL)		131.68 ± 100.58	116.55 ± 86.09	160.94 ± 118.53	<0.001
HDL-C (mg/dL)		52.75 ± 12.85	54.99 ± 13.11	48.41 ± 11.09	<0.001
BUN (mg/dL)		15.54 ± 4.90	15.35 ± 5.01	15.91 ± 4.67	<0.001
Crea (mg/dL)		0.81 ± 0.23	0.80 ± 0.23	0.84 ± 0.22	<0.001
FBG (mg/dL)		101.54 ± 23.54	98.45 ± 20.29	107.52 ± 27.85	<0.001
Insulin (μU/mL)		9.21 ± 10.10	7.33 ± 1.24	12.84 ± 14.32	<0.001
MetS		1,699 (28.0)	661 (16.5)	1,038 (520.2)	<0.001
MetS score		1.66 ± 1.37	1.22 ± 1.24	2.51 ± 1.21	<0.001
HOMA-IR		2.43 ± 3.62	1.84 ± 1.93	3.58 ± 5.42	<0.001

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; WC, waist circumference; LAP, lipid accumulation product index; TC, total cholesterol; TGs, triglycerides; HDL-C, high-density lipoprotein cholesterol; BUN, blood urea nitrogen; Crea, serum creatinine; FBG, fasting blood glucose; MetS, metabolic syndrome; MetS score, metabolic syndrome score; HOMA-IR, homeostasis model assessment of insulin resistance.

analyzed using cross-tabulations and independent-sample *t*-tests (**Table 1**). The characteristics of study participants based on LAP quartiles in the entire population (**Table 2**), non-obese group (**Table 3**), and obese group (**Table 4**) were analyzed using cross-tabulations and one-way analysis of variance (ANOVA) tests, with Scheffe post-hoc analysis. After adjusting for relevant variables in the entire population, non-obese group, and obese group, the relationship between LAP quartiles and FBG, insulin, and MetS scores was analyzed using analysis of covariance (ANCOVA) tests (**Table 5**). To assess the association between HOMA-IR (mean and standard error, M±SE) and LAP quartiles, the ANCOVA test was performed by applying three models (**Table 6**). Model 1 adjusted for age and gender, and Model 2 adjusted for smoking, drinking, and regular exercise in addition to Model 1. Model 3 adjusted for SBP, DBP, BUN, and Crea in addition to Model 2. All statistical significance was determined at $P < 0.05$.

3. Result

3.1. Clinical characteristics of the total participants

The clinical characteristics of the study participants are presented in **Table 1**. The M ± SD of BMI, WC, FBG, HOMA-IR, and LAP were 23.94 ± 3.59 kg/m^2, 84.07 ± 10.41 cm, 101.54 ± 23.54 mg/dL, 2.43 ± 3.62, and 36.06 ± 35.97, respectively. The mean values of BMI ($P < 0.001$), WC ($P < 0.001$), FBG ($P < 0.001$), HOMA-IR ($P < 0.001$), and LAP ($P < 0.001$) were significantly higher in the obese group compared to the non-obese group.

Table 2. Clinical characteristics of subjects according to the quartiles of LAP in the overall population [*n* (%); M ± SD; *n* = 6,090]

Variables	Lipid accumulation product (LAP)				*P*-value	Post-hoc analysis (Scheffe)
	[a]Quartile 1 (≤ 14.14) (*n* = 1,522)	[b]Quartile 2 (14.15 ~ 26.09) (*n* = 1,523)	[c]Quartile 3 (26.10 ~ 45.99) (*n* = 1,523)	[d]Quartile 4 (≥ 46.00) (*n* = 1,522)		
LAP	8.48 ± 3.50	19.81 ± 3.49	35.07 ± 5.62	80.88 ± 45.20	< 0.001	a<b<c<d
Age (years)	42.92 ± 16.68	52.51 ± 16.42	56.64 ± 15.60	54.82 ± 15.60	< 0.001	a<b<d<c
Men	532 (35.0)	616 (40.4)	745 (48.9)	821 (53.9)	< 0.001	
SBP (mmHg)	112.14 ± 14.54	119.16 ± 16.73	122.95 ± 15.78	124.82 ± 15.87	< 0.001	a<b<c<d
DBP (mmHg)	72.49 ± 8.95	75.02 ± 16.73	76.66 ± 9.19	78.54 ± 10.33	< 0.001	a<b<c<d
BMI (kg/m^2)	20.75 ± 2.21	23.22 ± 2.33	24.75 ± 2.71	27.04 ± 3.61	< 0.001	a<b<c<d
WC (cm)	73.00 ± 6.33	82.04 ± 6.40	87.36 ± 6.88	93.87 ± 8.46	< 0.001	a<b<c<d
TC (mg/dL)	183.44 ± 32.48	189.35 ± 36.08	194.56 ± 40.05	203.60 ± 39.88	< 0.001	a<b<c<d
TGs (mg/dL)	65.55 ± 23.17	90.67 ± 27.63	130.29 ± 37.19	240.23 ± 141.28	< 0.001	a<b<c<d
HDL-C (mg/dL)	60.89 ± 12.48	55.38 ± 12.13	49.85 ± 10.56	44.87 ± 10.10	< 0.001	a<b<c<d
BUN (mg/dL)	14.75 ± 4.44	15.51 ± 5.13	16.15 ± 5.06	15.75 ± 4.86	< 0.001	a<d
Crea (mg/dL)	0.77 ± 0.17	0.80 ± 0.26	0.83 ± 0.23	0.85 ± 0.24	< 0.001	a<b<c, d
FBG (mg/dL)	92.35 ± 13.59	98.32 ± 16.97	104.02 ± 22.80	111.48 ± 32.02	< 0.001	a<b<c<d
Insulin (μU/mL)	5.67 ± 4.20	7.70 ± 6.83	9.73 ± 7.35	13.75 ± 15.95	< 0.001	a<b<c<d
MetS	10 (0.7)	153 (10.1)	435 (28.7)	1,101 (72.5)	< 0.001	
MetS score	0.41 ± 0.65	1.15 ± 0.98	1.97 ± 1.01	3.13 ± 1.03	< 0.001	a<b<c<d
HOMA-IR	1.31 ± 1.07	1.92 ± 2.12	2.58 ± 2.47	3.93 ± 6.09	< 0.001	a<b<c<d

Abbreviation: See **Table 1**.

Table 3. Clinical characteristics subjects according to the quartiles of LAP in non-obesity [*n* (%); M ± SD; *n* = 4,014]

Variables	Lipid accumulation product (LAP)				*P*-value	Post-hoc analysis (Scheffe)
	[a]Quartile 1 (≤ 10.51) (*n* = 1,002)	[b]Quartile 2 (10.52 ~ 18.64) (*n* = 1,004)	[c]Quartile 3 (18.65 ~ 31.82) (*n* = 1,005)	[d]Quartile 4 (≥ 31.83) (*n* = 1,003)		
LAP	6.58 ± 2.72	14.39 ± 2.35	24.51 ± 3.77	54.19 ± 3.77	< 0.001	a<b<c<d
Age (years)	40.91 ± 16.44	49.52 ± 16.44	55.55 ± 15.84	58.49 ± 14.63	< 0.001	a<b<c<d
Men	328 (32.7)	373 (37.2)	420 (41.8)	487 (48.6)	< 0.001	
SBP (mmHg)	111.23 ± 14.36	115.86 ± 16.28	120.24 ± 16.78	124.29 ± 16.56	< 0.001	a<b<c<d
DBP (mmHg)	72.14 ± 8.99	73.83 ± 9.37	75.06 ± 9.34	76.69 ± 9.30	< 0.001	a<b<c<d
BMI (kg/m^2)	10.09 ± 1.95	21.81 ± 1.67	22.59 ± 1.49	23.24 ± 1.31	< 0.001	a<b<c<d
WC (cm)	70.66 ± 5.47	77.97 ± 5.08	81.76 ± 5.22	85.42 ± 5.28	< 0.001	a<b<c<d
TC (mg/dL)	182.43 ± 31.85	187.08 ± 35.14	194.73 ± 37.55	202.77 ± 39.61	< 0.001	a<b<c<d
TGs (mg/dL)	62.60 ± 22.91	80.01 ± 23.43	112.32 ± 30.57	211.25 ± 30.57	< 0.001	a<b<c<d
HDL-C (mg/dL)	62.20 ± 12.60	57.45 ± 12.63	53.24 ± 11.33	47.08 ± 10.87	< 0.001	d<c<b<a
BUN (mg/dL)	14.40 ± 4.20	15.27 ± 4.66	15.87 ± 6.00	15.84 ± 4.87	< 0.001	a<b, c, d
Crea (mg/dL)	0.76 ± 0.16	0.78 ± 0.18	0.81 ± 0.33	0.82 ± 0.22	< 0.001	a, b<c, d
FBG (mg/dL)	91.53 ± 12.93	95.58 ± 15.29	99.81 ± 18.60	106.87 ± 27.78	< 0.001	a<b<c<d
Insulin (μU/mL)	5.42 ± 3.39	6.36 ± 4.61	7.78 ± 7.77	9.77 ± 7.09	< 0.001	a<b<c<d
MetS	3 (0.3)	30 (3.0)	127 (12.7)	501 (50.0)	< 0.001	
MetS score	0.31 ± 0.57	0.74 ± 0.84	1.29 ± 1.00	2.56 ± 1.11	< 0.001	a<b<c<d
HOMA-IR	1.24 ± 0.85	1.52 ± 1.22	1.97 ± 2.44	2.64 ± 2.39	< 0.001	a<b<c<d

Abbreviation: See **Table 1**.

Table 4. Clinical characteristics of subjects according to the quartiles of LAP in obesity [*n* (%); M ± SD; *n* = 2,076]

Variables	Lipid accumulation product (LAP)				*P*-value	Post-hoc analysis (Scheffe)
	[a]Quartile 1 (≤ 30.23) (*n* = 519)	[b]Quartile 2 (30.24 ~ 46.69) (*n* = 519)	[c]Quartile 3 (46.70 ~ 69.71) (*n* = 519)	[d]Quartile 4 (≥ 69.72) (*n* = 519)		
LAP	21.83 ± 5.58	38.32 ± 4.69	57.13 ± 6.70	113.07 ± 56.00	< 0.001	a<b<c<d
Age (years)	50.44 ± 17.28	54.72 ± 15.66	54.33 ± 16.03	52.06 ± 15.35	< 0.001	a<b, c
Men	255 (49.1)	268 (51.6)	285 (54.9)	298 (57.4)	0.041	
SBP (mmHg)	120.66 ± 15.02	123.12 ± 14.50	124.40 ± 15.79	125.30 ± 15.61	< 0.001	a<c, d
DBP (mmHg)	76.13 ± 9.05	77.69 ± 9.56	78.30 ± 9.88	80.23 ± 10.92	< 0.001	a<d
BMI (kg/m^2)	26.71 ± 1.60	27.27 ± 2.02	28.02 ± 2.71	29.27 ± 3.42	< 0.001	a<b<c<d
WC (cm)	89.01 ± 2.99	92.51 ± 6.02	95.43 ± 6.80	98.87 ± 7.90	< 0.001	a<b<c<d
TC (mg/dL)	182.93 ± 35.93	191.00 ± 39.36	195.63 ± 37.20	208.98 ± 41.98	< 0.001	a<b, c<d
TGs (mg/dL)	79.72 ± 20.92	116.85 ± 25.97	161.02 ± 37.59	292.17 ± 164.10	< 0.001	a<b<c<d
HDL-C (mg/dL)	54.96 ± 11.42	49.29 ± 10.01	46.46 ± 9.35	42.93 ± 9.81	< 0.001	d<c<b<a
BUN (mg/dL)	15.87 ± 4.53	16.36 ± 4.69	15.74 ± 4.38	15.66 ± 5.05	0.076	
Crea (mg/dL)	0.82 ± 0.19	0.85 ± 0.20	0.86 ± 0.20	0.86 ± 0.25	0.011	a<c, d
FBG (mg/dL)	99.68 ± 17.71	105.64 ± 24.53	109.36 ± 29.32	115.41 ± 34.67	< 0.001	a<b, c<d
Insulin (μU/mL)	9.43 ± 7.40	11.28 ± 7.94	13.15 ± 8.99	17.50 ± 24.22	< 0.001	a<c<d
MetS	86 (16.6)	168 (32.5)	336 (64.9)	448 (86.8)	< 0.001	
MetS score	1.54 ± 0.97	2.14 ± 0.94	2.86 ± 0.98	3.52 ± 0.92	< 0.001	a<b<c<d
HOMA-IR	2.37 ± 2.16	3.07 ± 3.01	3.62 ± 3.24	5.25 ± 9.43	< 0.001	a<c<d

Abbreviation: See **Table 1**.

Table 5. Comparisons of FBG, insulin, and MetS score according to the quartiles of LAP in the overall population, non-obesity, and obesity (n = 6,090)

Variables	Category		FBG (mg/dL) M ± SE (95% CI)	Insulin (μU/mL) M ± SE (95% CI)	MetS score M ± SE (95% CI)
Overall population (n = 6,090)	Lap	Quartile 1	95.22 ± 0.60 (94.05 ~ 96.39)	5.09 ± 0.26 (4.58 ~ 5.61)	0.65 ± 0.02 (0.60 ~ 0.69)
		Quartile 2	98.37 ± 0.56 (97.26 ~ 99.48)	7.73 ± 0.25 (7.24 ~ 8.21)	1.15 ± 0.02 (1.11 ~ 1.19)
		Quartile 3	102.42 ± 0.57 (101.30 ~ 103.54)	10.03 ± 0.25 (9.54 ~ 10.52)	1.85 ± 0.02 (1.81 ~ 1.90)
		Quartile 4	110.17 ± 0.58 (109.04 ~ 111.30)	14.01 ± 0.25 (13.51 ~ 14.50)	3.01 ± 0.02 (2.97 ~ 3.05)
	P-value		< 0.001	< 0.001	< 0.001
Non-obesity (n = 4,014)	Lap	Quartile 1	94.52 ± 0.64 (93.28 ~ 95.77)	4.96 ± 0.20 (4.59 ~ 5.35)	0.54 ± 0.03 (0.49 ~ 0.59)
		Quartile 2	96.27 ± 0.60 (95.09 ~ 97.45)	6.30 ± 0.19 (5.93 ~ 6.67)	0.79 ± 0.02 (0.74 ~ 0.84)
		Quartile 3	98.64 ± 0.60 (97.46~99.82)	7.96 ± 0.19 (7.59 ~ 8.33)	1.19 ± 0.03 (1.15 ~ 1.24)
		Quartile 4	104.43 ± 0.62 (103.21 ~ 105.65)	10.14 ± 0.20 (9.75 ~ 10.52)	2.37 ± 0.03 (2.32 ~ 2.42)
	P-value		< 0.001	< 0.001	< 0.001
Obesity (n = 2,076)	Lap	Quartile 1	100.37 ± 1.20 (98.02 ~ 102.71)	9.05 ± 0.62 (7.83 ~ 10.28)	1.63 ± 0.04 (1.56 ~ 1.70)
		Quartile 2	105.06 ± 1.18 (102.74 ~ 107.37)	11.35 ± 0.62 (10.14 ~ 12.55)	2.12 ± 0.04 (2.04 ~ 2.19)
		Quartile 3	108.98 ± 1.18 (106.67 ~ 111.29)	13.22 ± 0.62 (12.12 ~ 14.53)	2.82 ± 0.04 (2.75 ~ 2.90)
		Quartile 4	115.62 ± 1.19 (113.30 ~ 117.95)	17.64 ± 0.62 (16.42 ~ 18.85)	3.48 ± 0.04 (3.41 ~ 3.56)
	P-value		< 0.001	< 0.001	< 0.001

Abbreviations: See **Table 1**; SE, standard error; CI, confidence interval. Adjusted for age, gender, smoking, drinking, regular exercising, SBP, DBP, BUN, and Crea.

Table 6. Comparisons of HOMA-IR according to the quartiles of LAP in overall population, non-obesity, and obesity (n = 6,090)

Variables	Category		HOMA-IR		
			Model 1	Model 2	Model 3
Overall population (n = 6,090)	Lap	Quartile 1	1.26 ± 0.09 (1.07 ~ 1.44)	1.26 ± 0.09 (1.07 ~ 1.44)	1.22 ± 0.09 (1.03 ~ 1.41)
		Quartile 2	1.92 ± 0.09 (1.75 ~ 2.10)	1.92 ± 0.09 (1.75 ~ 2.10)	1.92 ± 0.09 (1.75 ~ 2.10)
		Quartile 3	2.61 ± 0.09 (2.43 ~ 2.79)	2.61 ± 0.09 (2.43 ~ 2.78)	2.62 ± 0.09 (2.44 ~ 2.80)
		Quartile 4	3.95 ± 0.09 (3.77 ~ 4.13)	3.95 ± 0.09 (3.78 ~ 4.13)	3.98 ± 0.09 (3.80 ~ 4.16)
	P-value		< 0.001	< 0.001	< 0.001
Non-obesity (n = 4,014)	Lap	Quartile 1	1.21 ± 0.06 (1.09 ~ 1.33)	1.21 ± 0.06 (1.09 ~ 1.33)	1.19 ± 0.06 (1.06 ~ 1.31)
		Quartile 2	1.51 ± 0.06 (1.39 ~ 1.62)	1.51 ± 0.06 (1.39 ~ 1.62)	1.51 ± 0.06 (1.40 ~ 1.63)
		Quartile 3	1.99 ± 0.06 (1.87 ~ 2.10)	1.99 ± 0.06 (1.87 ~ 2.10)	1.99 ± 0.06 (1.88 ~ 2.11)
		Quartile 4	2.66 ± 0.06 (2.54 ~ 2.78)	2.66 ± 0.06 (2.54 ~ 2.78)	2.68 ± 0.06 (2.56 ~ 2.80)
	P-value		< 0.001	< 0.001	< 0.001
Obesity (n = 2,076)	Lap	Quartile 1	2.37 ± 0.24 (1.91 ~ 2.83)	2.36 ± 0.24 (1.90 ~ 2.82)	2.28 ± 0.24 (1.81 ~ 2.74)
		Quartile 2	3.08 ± 0.23 (2.62 ~ 3.54)	3.06 ± 0.23 (2.60 ~ 3.52)	3.06 ± 0.23 (2.60 ~ 3.52)
		Quartile 3	3.63 ± 0.23 (3.17 ~ 4.09)	3.66 ± 0.23 (3.20 ~ 4.12)	3.67 ± 0.23 (3.21 ~ 4.13)
		Quartile 4	5.24 ± 0.23 (4.79 ~ 5.70)	5.24 ± 0.23 (4.78 ~ 5.70)	5.31 ± 0.24 (4.85 ~ 5.77)
	P-value		< 0.001	< 0.001	< 0.001

Abbreviations: See **Table 1**. Model 1 (M ± SE [95% CI]), age and gender; Model 2 (M ± SE [95% CI]), Model 1 further adjusted for smoking, drinking, and regular exercising; Model 3 (M ± SE [95% CI]), Model 2 further adjusted for SBP, DBP, BUN, and Crea.

3.2. Clinical characteristics of participants based on LAP quartiles

The clinical characteristics of participants based on LAP quartiles in the entire population, non-obese group, and obese group are shown in **Tables 2**, **3**, and **4**, respectively. In the entire population, non-obese group, and obese group, BMI (all, $P < 0.001$), WC (all, $P < 0.001$), TC (all, $P < 0.001$), TGs (all, $P < 0.001$), FBG (all, $P < 0.001$), Insulin (all, $P < 0.001$), MetS score (all, $P < 0.001$), and HOMA-IR (all, $P < 0.001$) increased, except for insulin and HOMA-IR levels in the obese group, which only in LAP quartiles 3 and 4, while HDL-C (all, $P < 0.001$), decreased.

3.3. FBG, insulin, MetS score, and HOMA-IR based on LAP quartiles

FBG, insulin, MetS score, and HOMA-IR based on LAP quartiles in the entire population, non-obese group, and obese group are shown in **Tables 5** and **6**. After adjusting for age, gender, smoking habits, drinking habits, regular exercise habits, SBP, DBP, BUN, and Crea in the entire population, non-obese group, and obese group, the mean values (M ± SE, 95% confidence interval [CI]) of FBG (all, $P < 0.001$), insulin (all, $P < 0.001$), and MetS score (all, $P < 0.001$) increased with increasing LAP quartiles (**Table 5**). Furthermore, in the overall population, non-obese group, and obese group, after adjusting for relevant variables, the mean values (M ± SE, 95% CI) of HOMA-IR increased with increasing LAP quartiles (all, $P < 0.001$) (**Table 6**).

4. Discussion

This study investigated the relationship between LAP and insulin resistance in South Korean adults using data from the 2019 National Health and Nutrition Examination Survey. The findings showed that HOMA-IR increased with higher LAP not only in the obese group but also in the non-obese group. South Korea has seen a continuous rise in insulin resistance-related conditions such as MetS and DM along with an increasingly obese population, partly due to the westernization of dietary habits [14]. Dyslipidemia, including elevated TGs and decreased HDL-C, is known to have an inappropriate impact on maintaining FBG levels [15]. Particularly, the accumulation of intra-abdominal lipids can increase insulin resistance and accelerate the onset of T2DM [16]. According to previous studies, Shin reported that LAP is superior to other lipid-related indices such as TGs/HDL-C and TyG index in predicting MetS, a representative condition of insulin resistance, in a study targeting obese individuals aged 20 years and older [17]. Sun and colleagues, in a study conducted on Chinese adults aged 40 and above, found that LAP outperforms body obesity indices such as BMI and WC in predicting T2DM [area under the curve (AUC): 0.658, 95% CI: 0.645–0.671] and insulin resistance (AUC: 0.781, 95% CI: 0.771–0.792) [18]. Moreover, Mirmiran and his team reported that an increase in LAP is associated with increased insulin resistance, oxidative stress, and systemic inflammation in Iranian adults with diabetes [19].

In the results of this study, as LAP quartiles increase in the entire population, insulin levels ($P < 0.001$) increased, and indices related to insulin resistance, such as HOMA-IR ($P < 0.001$) and MetS score ($P < 0.001$), also increased. LAP is known as a gender-specific index using TGs and WC values to predict intra-abdominal lipid accumulation and intracellular lipid accumulation in various tissues [6,20]. Intracellular lipid accumulation in various tissues, such as the skeletal system and pancreatic beta cells, can lead to impaired insulin signaling and pathological responses [20]. As a result, it can have an inappropriate impact on the regulation of metabolic processes, including glycogen synthesis and breakdown, glucose uptake and oxidation, lipid storage, and lipolysis [6]. Chiang *et al*. argued that LAP is associated with an increase in adipocytokines, including plasminogen activator inhibitor-1 and interleukin-6, which are related to lipid breakdown and adipocytokine activity [21].

In this study, the analysis was conducted for the entire population, as well as for the obese and non-obese groups. Compared to the non-obese group, the obese group had higher levels of TGs, WC, FBG, and insulin, and LAP values were also higher. Obesity is characterized by the abnormal and excessive accumulation of fat in the body, often associated with chronic conditions. Obesity is related to dyslipidemia and hyperglycemia. The excess supply of fatty acids and glucose to the mitochondria in obesity can lead to the generation of reactive oxygen species (ROS) and oxidative stress, which are closely linked to insulin resistance [22]. Therefore, fat-related indices, insulin resistance-related indices, and LAP may be higher in the obese group compared to the non-obese group. In addition, in a state of chronic metabolic abnormalities, increased intra-abdominal lipid accumulation associated with obesity can further exacerbate insulin resistance.

In studies investigating the relationship between LAP and insulin resistance, most studies have been conducted on patients with chronic conditions such as T2DM and obesity [17-19]. While there are studies on non-diabetic adults who could be considered relatively metabolically normal when compared to individuals with chronic conditions, there is very little research on their relationship, especially in the context of normal-weight individuals. Xia and colleagues conducted a study on 2,524 non-diabetic Chinese adults and claimed that LAP is related to HOMA-IR and is a powerful predictor of insulin resistance, surpassing BMI and WC in predicting insulin resistance [23]. Taverna *et al*. reported that LAP is a strong and reliable predictor of insulin resistance and the incidence of MetS in non-diabetic Spanish adults [24]. Furthermore, Pineda *et al*. reported that the LAP index is an important predictor of the incidence of MetS, regardless of gender and BMI, in non-diabetic Venezuelan adults [25]. In the results of this study, both the obese and non-obese groups showed that as LAP increased, insulin, as well as indices related to insulin resistance, HOMA-IR, and MetS scores, increased. These results are likely attributed to the increase in intracellular lipid accumulation in various tissues, such as abdominal tissues and pancreatic beta cells, due to the increase in LAP [19], leading to increased insulin resistance, as well as insulin signaling disorders and increased oxidative stress [6].

In conclusion, this study used data from the 2019 National Health and Nutrition Examination Survey, representative of South Korea, to investigate the relationship between lipid accumulation indices and insulin resistance in South Korean adults. The study found that the lipid accumulation indices increased with insulin resistance not only in the obese group but also in the non-obese group.

However, this study has several limitations. Firstly, this study used HOMA-IR to evaluate insulin resistance. Some researchers argued that HOMA indices are more commonly used and useful in large-scale population studies of insulin resistance [26]. However, it is known that the gold-standard methods, such as the hyperglycemic clamp test and hyperinsulinemic-euglycemic clamp test, are more accurate than HOMA indices for measuring insulin resistance [27]. Hence, future research should consider using the gold standard method to study the relationship between LAP and insulin resistance. Secondly, this study did not include information on medication use as part of the criteria for MetS. Therefore, future research should consider incorporating information on medication use. Thirdly, this study is cross-sectional, and as such, it has limitations in explaining the precise causality between LAP and insulin resistance. Thus, it is expected that more accurate results can be obtained to confirm their causal relationship through cohort studies on LAP and insulin resistance in the future.

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Disclosure statement

The author declares no conflict of interest.

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