Inverse Association Between Triglyceride Glucose Index and Muscle Mass in Korean Adults: 2008–2011 KNHANES

Sung Ho Ahn
Gangnam Severance Hospital
Jun hyuk Lee
Severance Hospital
JI WON LEE (indi5645@yuhs.ac)
Department of Family Medicine, Yonsei University College of Medicine, Seoul, Republic of Korea
https://orcid.org/0000-0002-2666-4249

Research

Keywords: TyG index, sarcopenia, low skeletal muscle index, insulin resistance, chronic inflammation

Posted Date: September 22nd, 2020

DOI: https://doi.org/10.21203/rs.3.rs-78705/v1

Version of Record: A version of this preprint was published on November 22nd, 2020. See the published version at https://doi.org/10.1186/s12944-020-01414-4.

Abstract

Aim: The early detection and prevention of sarcopenia is increasingly emphasized considering that sarcopenia is an important risk factor for falls or cardiovascular disease. Recently, there have been emerging evidences that support the relationship between sarcopenia, insulin resistance, and inflammation. The TyG index, a novel surrogate marker of insulin resistance and systemic inflammation, has not yet been verified for an association with sarcopenia. This study aimed to examine the relationship between the TyG index and muscle mass in Korean adults.

Methods: This study included 15,741 non-diabetic adults over 19 years old using data from the 2008–2011 Korea National Health and Nutrition Examination Survey. Participants were divided into three groups according to tertiles of the TyG index. Low skeletal muscle mass index (LMSI) was defined by the Foundation for the National Institutes of Health (FNIH) Sarcopenia Project criteria. Weighted multivariate logistic regression model was used to analyze the relationship between TyG index tertiles and LSMI.

Results: The ORs (95% CIs) for LSMI of the second and third tertiles, compared to first tertile, were 1.300 (1.001–1.689) and 1.448 (1.104–1.900), respectively, after adjusting for confounding factors. Higher TyG index was also associated with increased odds of LSMI in subgroups such as adults under 65-year old who did not exercise regularly, who consumed less than 30g alcohol per day, who did not currently smoke, and who ate less than 1.5g protein/kg/day.

Conclusion: The TyG index was significantly and positively associated with LSMI in Korean adults.

Introduction

Sarcopenia is defined as an involuntary loss of muscle mass, strength and performance that occurs with aging. [1] However, there is no unified criteria for diagnosing sarcopenia. [2–5] Typically, muscle mass decreases by 3–8% per decade after 30 years of age, and muscle strength, [6, 7] a major part of physical function, decreases by 1–2% per year after 50 years of age. [8, 9] For this reason, sarcopenia is mainly observed in the elderly, but it can occur in younger adults. [10] The estimated prevalence of sarcopenia has been reported to be at least 4.6% in all older adults and nearly 25% in hospitalized elderly patients. [11] Sarcopenia has become an increasingly important issue of public health as life spans have increased. [12, 13] Indeed, healthcare costs related to sarcopenia were estimated to be $18.5 billion ($10.8 billion in men, $7.7 billion in women) in the United States in 2000, constituting about 1.5% of total healthcare expenditures for the year. [13, 14]

Sarcopenia not only leads to increased risks of falls, fractures and disabilities, [15, 16] but also metabolic disorders such as insulin resistance, type 2 diabetes mellitus, dyslipidaemia, and hypertension [17] as a result of decreased basal metabolic rate, fat-free mass, and physical activity. Additionally, sarcopenia is associated with chronic, low-grade, systemic inflammation. [18–21] There have been several reports demonstrating the relationship between sarcopenia, insulin resistance, [22] and inflammation. [23]

The triglyceride and glucose index (TyG index), a product of triglyceride levels and fasting plasma glucose concentration, has recently been recognized as a useful clinical surrogate marker of insulin resistance [24, 25] and systemic inflammation. [26, 27] Moreover, the TyG index has been validated for predicting the risk of diabetes and cardiovascular disease syndrome [28–30] and for diagnosing metabolic syndrome. [31] However, to date there have been no studies of the relationship between the TyG index and sarcopenia. In this work, we investigated the association between TyG index and muscle mass in a representative sample of Korean adults.

Materials And Methods

Study population

All study data were obtained from the 2008–2011 Korea National Health and Nutrition Examination Survey (KNHANES), a nationwide representative survey conducted by the Korea Centers for Disease Control and Prevention to assess the health and nutritional status of Koreans. The KNHANES has a cross-sectional, stratified, multistage, probability sampling design based on age, sex, and geographical area. Sample weights were assigned to participants to capture a sample representing the general Korean population. Survey items in the KNHANES have been changed partly due to the availability of survey resources and some questionnaires are updated and change with the year. [32] Detailed methods related to the KNHANES have been previously described. [32]

A total 37,753 of individuals participated in the 2008–2011 KNHANES. Of these participants, we excluded those who: were under 19 years old (n = 9,736); had been treated for type 2 diabetes mellitus or had fasting plasma glucose levels 126 mg/dL or more (n = 6,177); were missing DXA data (n = 6,445); were missing BMI data (n = 13); or were missing serum triglyceride data (n = 1). In total, 15,741 participants (6,646 men and 9,095 women) were included in this analysis (Fig. 1).

Biochemical measurements

Blood samples were collected from the antecubital vein from each patient after at least 8 hours of fasting. Serum total cholesterol, triglycerides, high-density lipoprotein (HDL)-cholesterol and plasma glucose concentrations were measured using a Hitachi 7600 Analyzer. WBC counts were analysed using a XE-2100D blood cell counter. The TyG index was calculated as follows: log [serum triglycerides (mg/dL) × plasma glucose (mg/dL)/2]. At present, there is no reference value for the TyG index that predicts sarcopenia. Therefore, we divided participants into three groups according to tertiles of the TyG index: T1 (6.45–8.19), T2 (8.20–8.71), and T3 (8.72–11.29).

Assessment of muscle mass

Whole-body dual-energy X-ray absorptiometry (DXA) was performed from July 2008 to June 2011 to evaluate body composition (QDR 4500A; Hologic Inc., Bedford, MA, USA). Body composition data were obtained from the predefined anatomical regions as follows: head, arms, legs, trunk, pelvic region, and

whole body. Participants were analysed for bone mineral content (g), bone mineral density (g/cm^2), fat mass (g), lean body mass (g), and total fat percentage (fat mass/total mass × 100). Skeletal muscle mass was calculated using the following equation: lean body mass (g) - bone mineral content (g). The appendicular skeletal muscle mass (ASM) was calculated as the sum of the skeletal muscle mass of both the arms and legs. We defined the skeletal muscle mass index (SMI) as ASM (kg) divided by body mass index (BMI) (kg/m^2). Finally, the low skeletal muscle index (LSMI) was defined according to the Foundation for the National Institutes of Health (FNIH) Sarcopenia Project criteria: SMI values less than 0.789 for men and less than 0.512 for women. [5]

Measurement of anthropometric and clinical parameters

Height (cm) and body weight (kg) were estimated to the nearest 0.1 cm by using a stadiometer without shoes in standing posture or supine position and 0.1 kg by digital scale in light clothing, respectively. BMI was calculated as body weight divided by height squared (kg/m^2). Adults with a BMI greater than or equal to 25 kg/m^2 were considered overweight and those with a BMI less than 18.5 kg/m^2 were considered underweight according to the guidelines of the International Obesity Task Force of the World Health Organization. [33] Adults were categorized into three different categories of smoking status: current smokers, ex-smokers, and never smokers. We defined a current smoker as someone who smoked at the time of the interview and had smoked at least 100 cigarettes over their lifetime. Ex-smokers were defined as those who did not currently smoke but who had smoked at least 100 cigarettes in his or her lifetime. Heavy alcohol use was defined as consuming an average of 30 g or more of alcohol per day. We defined regular exercise as 20 minutes of vigorous exercise at least 3 days per week or 30 minutes of moderate exercise/walking at least 5 days per week, and physical activity was assessed using the International Physical Activity Questionnaire (IPAQ). A food frequency questionnaire (FFQ) was used for all adults aged 19 years or older. Daily nutritional intake of total calorie (kcal/day), carbohydrate (CHO) (g/day), fat (g/day), and protein (g/day) were surveyed. Based on the modified NCEP ATP-III criteria, [34] we defined metabolic syndrome according to the following criteria: (1) waist circumference ≥ 90 cm in men and ≥ 85 cm in women, per the Korean-specific cut-offs for abdominal obesity of the Korean Society of Obesity; [35] (2) serum triglycerides ≥ 150 mg/dL; (3) either fasting plasma glucose ≥ 100 mg/dL, the use of anti-diabetic medications, or current treatment with insulin therapy; (4) HDL cholesterol < 40 mg/dL in men or < 50 mg/dL in women or use of lipid-lowering medications; (5) blood pressure ≥ 130/85 mmHg or use of anti-hypertensive medications. Detailed information about the KNHANES is available through the KNHANES website (http://knhanes.cdc.go.kr).

Statistical analysis

All data were presented as mean or percentage (%) ± standard error (SE) values. For the analysis of clinical characteristics of the study population, a weighted analysis of variance (ANOVA) test was used for continuous variables. For categorical variables, weighted chi-square tests were used to compare differences among the three groups. After adjusting for confounding variables, a weighted multivariate logistic regression analysis was performed to calculate the odds ratios (ORs) with 95% confidence intervals (CIs) for LSMI according to the TyG index tertiles. We further analysed subgroups according to

age, alcohol drinking status, smoking status, amount of protein intake and regular exercise through a weighted multivariate logistic regression analysis. All statistical analyses were conducted using SPSS statistical software (version 25.0; SPSS Inc., Chicago, IL, USA). The significance level was set at p less than 0.05.

Results

General characteristics of the study population

Table 1 represents the clinical characteristics of 15,741 subjects according to tertile of the TyG index. The proportion of men and the mean age were lowest in T1 and highest in T3. The mean value of waist circumference, BMI, mean blood pressure, blood leukocyte count, fasting plasma glucose levels, serum total cholesterol levels, and log-transformed triglyceride levels increased, whereas HDL cholesterol levels decreased with each increase in TyG index tertiles. The proportion of heavy alcohol drinkers, current smokers, and number of chronic diseases increased along with TyG index tertiles. The proportion of adults participating in regular exercise was highest in T1 and lowest in T3, although these trends were not statistically significant. The average amount of daily calorie intake, carbohydrate intake, and protein intake significantly increased with increasing TyG index tertiles, but the amount of daily fat intake decreased with increasing TyG index tertiles. The mean value of the SMI decreased with increasing TyG index tertiles for both men and women. The prevalence of LSMI increased with increasing TyG index tertiles (Fig. 2). The number of components of metabolic syndrome was higher in T3 than T1. WBC counts were increased with an increase in the TyG index tertiles.

Table 1
Clinical characteristics of three different population

2008–2011 KNHANES					
TyG index	**T1**	**T2**	**T3**	**Total**	*P*
	6.45–8.19	8.20–8.71	8.72–11.29		
N	5,229	5,235	5,277	15,741	
Male sex, % (SE)	35.2 (0.9)	49.3 (0.9)	64.2 (0.8)	49.3 (0.5)	< 0.001
Age, years	38.3 ± 0.3	44.3 ± 0.3	47.7 ± 0.3	43.4 ± 0.2	< 0.001
Waist circumference, cm	75.2 ± 0.2	80.2 ± 0.2	85.5 ± 0.2	80.3 ± 0.1	< 0.001
Mean blood pressure, mmHg	85.4 ± 0.2	90.3 ± 0.3	94.5 ± 0.3	90.1 ± 0.2	< 0.001
Leukocyte count (*1,000/μL)	5.6 ± 0.0	6.0 ± 0.0	6.6 ± 0.0	6.1 ± 0.0	< 0.001
Glucose, mg/dL	88.0 ± 0.1	92.2 ± 0.2	96.9 ± 0.2	92.3 ± 0.1	< 0.001
Log-transformed Triglyceride, mg/dL	4.0 ± 0.0	4.6 ± 0.0	5.3 ± 0.0	4.7 ± 0.0	< 0.001
Employment status, % (SE)	63.6 (0.9)	62.9 (1.0)	68.1 (0.9)	64.8 (0.6)	< 0.001
Heavy alcohol use, % (SE)	5.2 (0.5)	7.5 (0.5)	13.8 (0.7)	8.8 (0.3)	< 0.001
Current smoker, % (SE)	18.5 (0.8)	25.3 (0.9)	38.0 (1.0)	27.0 (0.6)	< 0.001
Regular exercise, % (SE)	25.5 (0.8)	25.4 (0.8)	24.0 (0.8)	25.0 (0.5)	0.307
Daily calorie intake, kcal/day	1982.3 ± 16.5	2010.0 ± 17.3	2125.7 ± 20.1	2039.3 ± 11.1	< 0.001
Daily protein intake, % of total calorie intake	14.6 ± 0.1	14.4 ± 0.1	14.2 ± 0.1	14.4 ± 0.1	0.001
SMI					
Men	1.006 ± 0.004	0.963 ± 0.004	0.921 ± 0.003	0.963 ± 0.002	< 0.001

Abbreviations: TyG index, triglyceride-glucose index; KNHANES, Korean National Health and Nutrition Examination Survey; SE, standard error; BMI, body mass index; SMI, skeletal muscle mass index.

	2008–2011 KNHANES				
Women	0.666 ± 0.002	0.629 ± 0.002	0.596 ± 0.002	0.631 ± 0.002	< 0.001
Number of components of metabolic syndrome	0.89 ± 0.78	1.55 ± 1.01	1.47 ± 0.92		< 0.001
0	56.3 (0.9)	30.9 (0.9)	3.4 (0.4)	30.6 (0.5)	
1	33.0 (0.8)	39.5 (0.9)	15.4 (0.7)	29.3 (0.5)	
2	8.4 (0.5)	20.0 (0.7)	29.8 (0.9)	19.2 (0.4)	
3	2.0 (0.2)	8.3 (0.4)	28.9 (0.9)	12.9 (0.4)	
4	0.2 (0.1)	1.3 (0.2)	17.8 (0.6)	6.3 (0.2)	
5	-	-	4.8 (0.3)	1.6 (0.1)	
Number of chronic diseases, % (SE)					< 0.001
0	95.6 (0.4)	93.1 (0.4)	92.1 (0.5)	93.5 (0.3)	
1	4.0 (0.3)	6.2 (0.4)	7.2 (0.4)	5.8 (0.2)	
≥2	0.4 (0.1)	0.7 (0.1)	0.7 (0.1)	0.6 (0.1)	

Abbreviations: TyG index, triglyceride-glucose index; KNHANES, Korean National Health and Nutrition Examination Survey; SE, standard error; BMI, body mass index; SMI, skeletal muscle mass index.

P was derived from weighted generalized linear regression analysis for continuous variables and weighted chi-square test for categorical variables.

Association between TyG index and LSMI

Table 2 shows the results of multivariate logistic regression analysis, including the ORs (95% CIs) for LSMI according to the TyG index tertiles. The ORs (95% CIs) for LSMI of T3 of TyG index versus T1 was 3.549 (2.897–4.347). This relationship remained significant after adjusting for age, sex, waist circumference, regular exercise, employment status, heavy alcohol use, smoking status, daily protein intake, number of chronic diseases and total cholesterol levels (T3 vs. T1, ORs = 1.448, 95% CIs: 1.104–1.900, $p = 0.028$).

Table 3 represents the results of subgroup analysis showing the relationship between TyG index and LSMI. The adjusted ORs (95% CIs) for LSMI of T3 compared to T1 were 2.020 (1.403–2.908) in adults under 65 years of age, 1.513 (1.153–1.984) in adults who drank less than 30 g alcohol per day, 1.449 (1.096–1.916) in the non-current-smoker groups, and 1.456 (1.071–1.981) in adults who consumed less than 1.5 g protein per kg bodyweight per day. Similar trends were seen in males (T3 vs. T1, ORs = 1.611, 95% CIs = 1.013–2.562, $p = 0.121$), adults who did not exercise regularly (T3 vs. T1, ORs = 1.422, 95% CIs

= 1.058–1.912, $p = 0.056$), and adults with a healthy body weight (T3 vs. T1, ORs = 1.588, 95% CIs = 1.065–2.366, $p = 0.065$); however, these trends were not significant. There were no significant differences between groups among females, adults over 65 years of age, those who regularly exercised, overweight adults, heavy alcohol drinkers, current smokers, or those who consumed more than 1.5 g protein per kg bodyweight per day.

Table 2
Association between TyG index and LSMI

	Odds ratio with 95% confidence interval			*P*
	T1	**T2**	**T3**	
Unadjusted	1 (reference)	2.223 (1.781–2.776)	3.549 (2.897–4.347)	< 0.001
Model 1	1 (reference)	1.357 (1.067–1.725)	1.587 (1.260–2.000)	< 0.001
Model 2	1 (reference)	1.300 (1.001–1.689)	1.448 (1.104–1.900)	0.028
Abbreviations: TyG index, triglyceride-glucose index; LSMI, low skeletal muscle mass index.				

Model 1: Adjusted for age, sex, waist circumference, and regular exercise.

Model 2: Adjusted for variables included in Model 1 plus employment status, alcohol use, smoking status, daily protein intake, number of chronic diseases, and total cholesterol.

SMI was defined using the following equation: ASM (kg)/BMI (kg/m^2).

We defined the LSMI according to the cut-off value of SMI based on the Foundation for the National Institutes of Health (FNIH) sarcopenia project criteria: SMI less than 0.789 for men and SMI less than 0.512 for women.

The odds ratio and 95% confidence interval were calculated using the weighted multivariate logistic regression analysis to evaluate the relationship between TyG index and LSMI.

Table 3
Subgroup analysis for relationships between TyG index and LSMI by using multivariate logistic regression analysis

	Odds ratio with 95% confidence interval			*P*
	T1	T2	T3	
Gender				
Men	1 (reference)	1.343 (0.847–2.130)	1.611 (1.013–2.562)	0.121
Women	1 (reference)	1.264 (0.930–1.717)	1.363 (0.984–1.888)	0.172
Age groups				
< 65	1 (reference)	1.655 (1.178–2.324)	2.020 (1.403–2.908)	0.001
≥ 65	1 (reference)	0.977 (0.659–1.449)	1.035 (0.713–1.503)	0.921
Regular exercise				
Yes	1 (reference)	1.573 (0.861–2.877)	1.496 (0.835–2.682)	0.316
No	1 (reference)	1.215 (0.907–1.628)	1.422 (1.058–1.912)	0.056
Weight status				
Underweight	1 (reference)	N/A	N/A	N/A
Normal	1 (reference)	1.442 (1.013–2.052)	1.588 (1.065–2.366)	0.065
Overweight	1 (reference)	1.029 (0.703–1.506)	1.154 (0.797–1.670)	0.619
Heavy alcohol use				
<30 g/day	1 (reference)	1.367 (1.051–1.777)	1.513 (1.153–1.984)	0.012
≥30 g/day	1 (reference)	0.263 (0.057–1.216)	0.440 (0.084–2.307)	0.161
Current smoker				
Yes	1 (reference)	0.943 (0.472–1.887)	1.457 (0.721–2.945)	0.154

Abbreviations: TyG index, triglyceride-glucose index; LSMI, low skeletal muscle mass index.

	Odds ratio with 95% confidence interval			*P*
No	1 (reference)	1.390 (1.056–1.831)	1.449 (1.096–1.916)	0.028
Protein intake				
>1.5 g/kg/day	1 (reference)	1.028 (0.513–2.060)	1.578 (0.779–3.196)	0.202
≤1.5 g/kg/day	1 (reference)	1.353 (1.002–1.826)	1.456 (1.071–1.981)	0.056
Abbreviations: TyG index, triglyceride-glucose index; LSMI, low skeletal muscle mass index.				

Each *P*-value was calculated by multivariate logistic regression analysis after adjusting for all confounders (age, sex, waist circumference, regular exercise, employment status, alcohol use, smoking status, daily protein intake, number of chronic diseases, and total cholesterol) except for the variable used in each subgroup analysis.

Discussion

The prevention of frailty is an important strategy to address related comorbidities such as falls, cardiovascular events, cognitive impairment, and mortality. [36, 37] The cycle of frailty consists of four main components: reduced resting metabolic rate, decreased total energy expenditure, chronic undernutrition, and sarcopenia. [38] Of these, sarcopenia is of particular importance for enabling the activities of daily living, preventing falls, and reducing various metabolic diseases.[37,38] Therefore, methods for the early detection and prevention of sarcopenia would be of clinical and societal value.

In this study, adults of both sexes who had higher a TyG index were more likely to have LSMI, even after adjusting for age and other confounding factors. These findings were based on data from a representative, nationwide, cross-sectional survey. The exact mechanism by which TyG index is positively associated with LSMI is not known, but we hypothesize that insulin resistance and chronic inflammation may be the major link between elevated TyG index and increased risk of sarcopenia. The pathogenesis of sarcopenia has been suggested to be closely related to chronic inflammation, [20] which consequently increases insulin resistance [39] and may be reflected as an increased TyG index. The TyG index is thought to represent insulin resistance because it is calculated on the basis of two metabolic parameters: serum triglycerides and fasting glucose. Although we could not directly investigate the association between TyG index and insulin resistance indices due to lack of insulin data in the 2008–2011 KNHANES, we did find that the TyG index was related to the severity of metabolic syndrome, which is closely associated with insulin resistance. [24, 40] In addition, we found that a higher TyG index was associated with higher blood leukocyte count, a marker of chronic inflammation [41].

Sarcopenia is accompanied by muscle fat accumulation and an increase in pro-inflammatory cytokines, such as interleukin-6 (IL-6) and tissue necrosis factor alpha (TNF-α) within myocytes, [42], [43] which contribute to subsequent decreases in muscle mass and strength. [44, 45] IL-6 downregulates glucose transporter 4 expression and insulin receptor substrate-1 (IRS-1), resulting in reduced transport of glucose into cells (including myocytes), and aggravating insulin resistance. [46] TNF-α initiates a wide range of downstream signalling cascades, such as the activation of nuclear factor kappa B (NF-κB) and c-Jun N-terminal kinase (JNK). [47, 48] In turn, NF-κB and JNK lead to the impairment of IRS-1 and aggravation of insulin resistance. [47] Moreover, upregulated NF-κB caused by pro-inflammatory cascades causes ubiquitination of muscle proteins and dissociation of actin and myosin filaments, which consequently leads to further loss of skeletal muscle. [49, 50]

In the subgroup analysis, although adults under 65 years had higher odds of LSMI with increasing higher TyG tertile, there was no relationship between TyG index and LSMI in adults over 65 years of age. We believe that adults over 65 years may be less affected by the TyG index than the younger group because of the dominant influence of other factors, such as aging, chronic diseases, physical activity, and nutrition, which could each exert a stronger effect on LSMI than the TyG index. [51] Although adults who regularly exercised did not have significantly increased odds of LSMI as a function of increasing TyG tertile, adults who did not regularly exercise did. Although the IPAQ does not provide information about the timing of exercise and or type/duration of physical activity, the negative effects caused by insulin resistance and chronic inflammatory reactions might be offset by the protective and anabolic signalling due to regular exercise. [52, 53] The relationship between the TyG index and LSMI was only significant in the subgroup of adults that did not drink more than 30 g alcohol per day. Prior evidence has suggested that heavy alcohol drinking may accelerate sarcopenia, [54] so we think that alcohol use may interfere with the relationship between TyG index and LSMI. Similarly, smoking causes oxidative stress and chronic inflammation,[56] and we only observed a significant relationship between TyG index and LSMI among the non-smoker group. One notable result in our subgroup study was that, in the low protein-intake group, the adjusted OR of LSMI in T3 compared to T1 was 1.456 (1.071–1.981). Supplementation with protein and amino acids may stimulate the synthesis of muscle protein, [55–57] eventually leading to gains in muscle mass. These results support a target consumption of at least 1.5 g protein per kg weight per day, especially in patients at high risk of sarcopenia.

This study had several limitations. First, we only had access to muscle mass information and could not obtain muscle strength or performance data, precluding a direct diagnosis of sarcopenia among the adults in this study. Second, we could not compare TyG indices with an insulin resistance index such as HOMA-IR. Finally, due to the cross-sectional study design, we could not assess causality between TyG index and LSMI. However, this is the first study to confirm the relationship between TyG index and muscle mass through the use of DXA and a representative, nationwide dataset from Korean adults.

In conclusion, we found that the TyG index was independently and negatively associated with muscle mass in Korean adults over 19 years old. Because the TyG index can be easily measured in the clinical setting, this may serve as a helpful method for the early detection of sarcopenia and related

comorbidities, thus enabling timely initiation of treatment. Longitudinal cohort studies and experimental studies are needed to confirm the relationship between TyG and sarcopenia.

Declarations

Acknowledgments

This work was supported by the Technology Innovation Program (20002781, A Platform for Prediction and Management of Health Risk Based on Personal Big Data and Lifelogging) funded by the Ministry of Trade, Industry & Energy (MOTIE, Korea). This work was supported by the pilot study of the Korea National Health and Nutrition Examination Survey linked Cause of death data by the Korea Centers for Disease Control and Prevention.

Funding

This research did not receive any specific funding from agencies in the public, commercial or not-for-profit sectors.

Disclosure of interest

The authors have no conflicts of interest related to this research to report.

Data availability

The dataset used in this study (KNHANES) can be provided by the Korea Centers for Disease Control and Prevention (http://www.cdc.go.kr/CDC/eng/main.jsp) after submission and evaluation of an appropriate research proposal.

References

1. Morley JE, Baumgartner RN, Roubenoff R, Mayer J, Nair KSJJoL. Medicine C Sarcopenia. 2001;137(4):231–43.
2. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, et al. Sarcopenia: European consensus on definition and diagnosisReport of the European Working Group on Sarcopenia in Older PeopleA. J Cruz-Gentoft et al. 2010;39(4):412–23.
3. Fielding RA, Vellas B, Evans WJ, Bhasin S, Morley JE, Newman AB, et al. Sarcopenia: an undiagnosed condition in older adults. Current consensus definition: prevalence, etiology, and consequences. International working group on sarcopenia. 2011;12(4):249–56.
4. Chen L-K, Liu L-K, Woo J, Assantachai P, Auyeung T-W, Bahyah KS, et al. Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia. 2014;15(2):95–101.
5. Studenski SA, Peters KW, Alley DE, Cawthon PM, McLean RR, Harris TB, et al. The FNIH sarcopenia project: rationale, study description, conference recommendations, and final estimates.

2014;69(5):547 – 58.
6. Holloszy JO. The biology of aging. In. Mayo Clinic Proceedings: Elsevier; 2000. p. S3-S9.
7. III Khosla LJM, Crowson S, O'Connor CS, O'Fallon MK. WM, Riggs BLJJotAGS. Epidemiology of sarcopenia. 2000;48(6):625–30.
8. Harris TJTJon. Muscle mass and strength: relation to function in population studies. 1997;127(5):1004S-6S.
9. Metter EJ, Conwit R, Tobin J, Fozard JLJTJoGSABS, Sciences M. Age-associated loss of power and strength in the upper extremities in women and men. 1997;52(5):B267-B76.
10. Shafiee G, Keshtkar A, Soltani A, Ahadi Z, Larijani B, Heshmat RJJoD, et al. Prevalence of sarcopenia in the world: a systematic review and meta-analysis of general population studies. 2017;16(1):21.
11. Patel HP, Syddall HE, Jameson K, Robinson S, Denison H, Roberts HC, et al. Prevalence of sarcopenia in community-dwelling older people in the UK using the European Working Group on Sarcopenia in Older People (EWGSOP) definition: findings from the Hertfordshire Cohort Study (HCS). 2013;42(3):378–84.
12. Bruyère O, Beaudart C, Locquet M, Buckinx F, Petermans J, Reginster J-YJEgm. Sarcopenia as a public health problem. 2016;7(3):272–5.
13. Beaudart C, Rizzoli R, Bruyère O, Reginster J-Y, Biver EJAoPH. Sarcopenia: burden challenges for public health. 2014;72(1):45.
14. Janssen I, Shepard DS, Katzmarzyk PT, Roubenoff RJJotAGS. The healthcare costs of sarcopenia in the United States. 2004;52(1):80–5.
15. Yeung SS, Reijnierse EM, Pham VK, Trappenburg MC, Lim WK, Meskers CG, et al. Sarcopenia and its association with falls and fractures in older adults: A systematic review and meta-analysis. 2019;10(3):485–500.
16. Benjumea A-M, Curcio C-L, Duque G, Gomez FJOaMjoms. Dynapenia and sarcopenia as a risk factor for disability in a falls and fractures clinic in older persons. 2018;6(2):344.
17. Karakelides H, Nair KSJCtidb. Sarcopenia of aging and its metabolic impact. 2005;68:123–48.
18. Dalle S, Rossmeislova L, Koppo KJFip. The role of inflammation in age-related sarcopenia. 2017;8:1045.
19. Meng S-J, Yu L-JJljoms. Oxidative stress, molecular inflammation and sarcopenia. 2010;11(4):1509–26.
20. Beyer I, Mets T, Bautmans IJCOiCN, Care M. Chronic low-grade inflammation and age-related sarcopenia. 2012;15(1):12–22.
21. Jensen, GLJJop, nutrition e. Inflammation: roles in aging and sarcopenia. 2008;32(6):656-9.
22. Du Y, Oh C. No JJJoo, syndrome m. Associations between sarcopenia and metabolic risk factors: A systematic review and meta-analysis. 2018;27(3):175.
23. Schaap LA, Pluijm SM, Deeg DJ, Visser MJTAjom. Inflammatory markers and loss of muscle mass (sarcopenia) and strength. 2006;119(6):526. e9-. e17.

24. Simental-Mendía LE, Rodríguez-Morán M. Guerrero-Romero FJMs, disorders r. The product of fasting glucose and triglycerides as surrogate for identifying insulin resistance in apparently healthy subjects. 2008;6(4):299–304.
25. Guerrero-Romero F, Simental-Mendía LE, González-Ortiz M, Martínez-Abundis E, Ramos-Zavala MG, Hernández-González SO, et al. The product of triglycerides and glucose, a simple measure of insulin sensitivity. Comparison with the euglycemic-hyperinsulinemic clamp. 2010;95(7):3347–51.
26. Park K, Ahn CW, Lee SB, Kang S, Nam JS, Lee BK, et al. Elevated TyG Index Predicts Progression of Coronary Artery Calcification. 2019;42(8):1569–73.
27. Mazidi M, Kengne A-P, Katsiki N, Mikhailidis DP. Banach MJJoD, Complications i. Lipid accumulation product and triglycerides/glucose index are useful predictors of insulin resistance. 2018;32(3):266–70.
28. Sánchez-Íñigo L, Navarro-González D, Fernández-Montero A, Pastrana-Delgado J, Martínez JAJEJoCI. The TyG index may predict the development of cardiovascular events. 2016;46(2):189–97.
29. Lee S-H, Kwon H-S, Park Y-M, Ha H-S, Jeong SH, Yang HK, et al. Predicting the development of diabetes using the product of triglycerides and glucose: the Chungju Metabolic Disease Cohort (CMC) study. 2014;9(2).
30. Navarro-González D, Sánchez-Íñigo L, Pastrana-Delgado J, Fernández-Montero A, Martinez JAJPm. Triglyceride–glucose index (TyG index) in comparison with fasting plasma glucose improved diabetes prediction in patients with normal fasting glucose: the Vascular-Metabolic CUN cohort. 2016;86:99–105.
31. Shin K-AJBSL. Triglyceride and glucose (TyG) index is a clinical surrogate marker for the diagnosis of metabolic syndrome. 2017;23(4):348–54.
32. Kweon S, Kim Y, Jang M-j, Kim Y, Kim K, Choi S, et al. Data resource profile: the Korea national health and nutrition examination survey (KNHANES). 2014;43(1):69–77.
33. Bassett JJHCA, Sydney. Organization WH. (2000) The Asia-Pacific perspective: redefining obesity and its treatment.
34. Grundy SM, Cleeman JI, Daniels SR, Donato KA, Eckel RH, Franklin BA, et al. Diagnosis and management of the metabolic syndrome: an American Heart Association/National Heart, Lung, and Blood Institute scientific statement. 2005;112(17):2735–52.
35. Lee SY, Park HS, Kim DJ, Han JH, Kim SM, Cho GJ, et al. Appropriate waist circumference cutoff points for central obesity in Korean adults. 2007;75(1):72–80.
36. Rockwood K, Stadnyk K, MacKnight C, McDowell L, Hébert RJL. A brief clinical instrument to classify frailty in elderly people. 1999;353(9148):205–6.
37. Speechley M, Tinetti MJJotAGS. Falls and injuries in frail and vigorous community elderly persons. 1991;39(1):46–52.
38. Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J, et al. Frailty in older adults: evidence for a phenotype. 2001;56(3):M146-M57.

39. Rehman K, Akash MSHJJobs. Mechanisms of inflammatory responses and development of insulin resistance: how are they interlinked? 2016;23(1):87.
40. Unger G, Benozzi SF, Perruzza F, Pennacchiotti GLJEyN. Triglycerides and glucose index: a useful indicator of insulin resistance. 2014;61(10):533–40.
41. Chmielewski PP, Strzelec BJFm. Elevated leukocyte count as a harbinger of systemic inflammation, disease progression, and poor prognosis: a review. 2018;77(2):171–8.
42. Krebs M, Roden MJD, Obesity M. Molecular mechanisms of lipid-induced insulin resistance in muscle. liver vasculature. 2005;7(6):621–32.
43. Guo, ZJLih, disease. Intramyocellular lipid kinetics and insulin resistance. 2007;6(1):18.
44. Alemán H, Esparza J, Ramirez FA, Astiazaran H, Payette HJA. ageing. Longitudinal evidence on the association between interleukin-6 and C-reactive protein with the loss of total appendicular skeletal muscle in free-living older men and women. 2011;40(4):469–75.
45. Bautmans I, Onyema O, Van Puyvelde K, Pleck S. Mets TJTjon, health, aging. Grip work estimation during sustained maximal contraction: validity and relationship with dependency and inflammation in elderly persons. 2011;15(8):731–6.
46. Chen L, Chen R, Wang H, Liang FJljoe. Mechanisms linking inflammation to insulin resistance. 2015;2015.
47. Aguirre V, Uchida T, Yenush L, Davis R, White MFJJoBC. The c-Jun NH2-terminal kinase promotes insulin resistance during association with insulin receptor substrate-1 and phosphorylation of Ser307. 2000;275(12):9047–54.
48. Chen G, Goeddel DVJS. TNF-R1 signaling: a beautiful pathway. 2002;296(5573):1634–5.
49. Powers SK, Kavazis AN, McClung JMJJoap. Oxidative stress and disuse muscle atrophy. 2007;102(6):2389–97.
50. Buford TW, Cooke MB, Manini TM, Leeuwenburgh C, Willoughby DSJJoGSABS, Sciences M. Effects of age and sedentary lifestyle on skeletal muscle NF-κB signaling in men. 2010;65(5):532–7.
51. Kuk JL, Ardern ClJDc. Age and sex differences in the clustering of metabolic syndrome factors: association with mortality risk. 2010;33(11):2457–61.
52. Montero-Fernandez N, Serra-Rexach JJEJPRM. Role of exercise on sarcopenia in the elderly. 2013;49(1):131–43.
53. Phu S, Boersma D, Duque GJJoCD. Exercise sarcopenia. 2015;18(4):488–92.
54. Song DS, Chang UI, Choi S, Jung YD, Han K, Ko S-H, et al. Heavy Alcohol Consumption with Alcoholic Liver Disease Accelerates Sarcopenia in Elderly Korean Males: The Korean National Health and Nutrition Examination Survey 2008–2010. 2016;11(9):e0163222-e.
55. Milne AC, Potter J, Vivanti A, Avenell AJCdosr. Protein and energy supplementation in elderly people at risk from malnutrition. 2009(2).
56. Paddon-Jones D, Sheffield-Moore M, Katsanos CS, Zhang X-J, Wolfe, RRJEg. Differential stimulation of muscle protein synthesis in elderly humans following isocaloric ingestion of amino acids or whey

protein. 2006;41(2):215–9.

57. Paddon-Jones D, Sheffield-Moore M, Zhang X-J, Volpi E, Wolf SE, Aarsland A, et al. Amino acid ingestion improves muscle protein synthesis in the young and elderly. 2004;286(3):E321-E8.

Figures

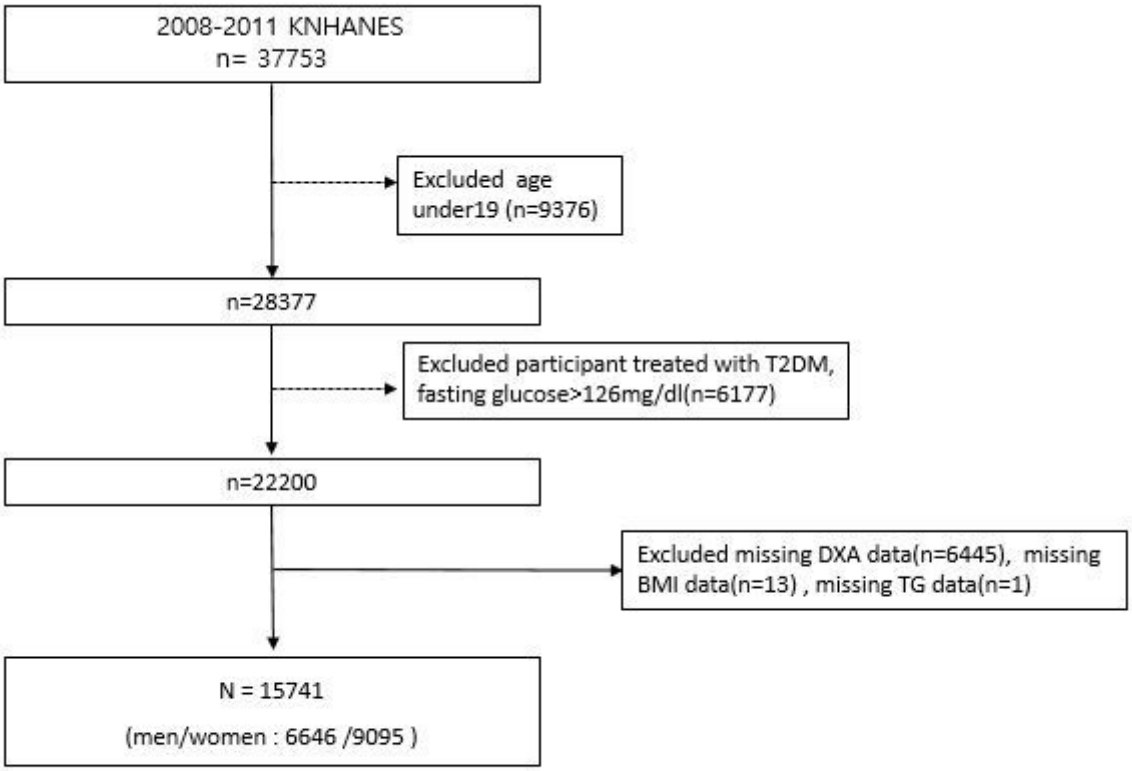

Figure 1

Flowchart of study population selection

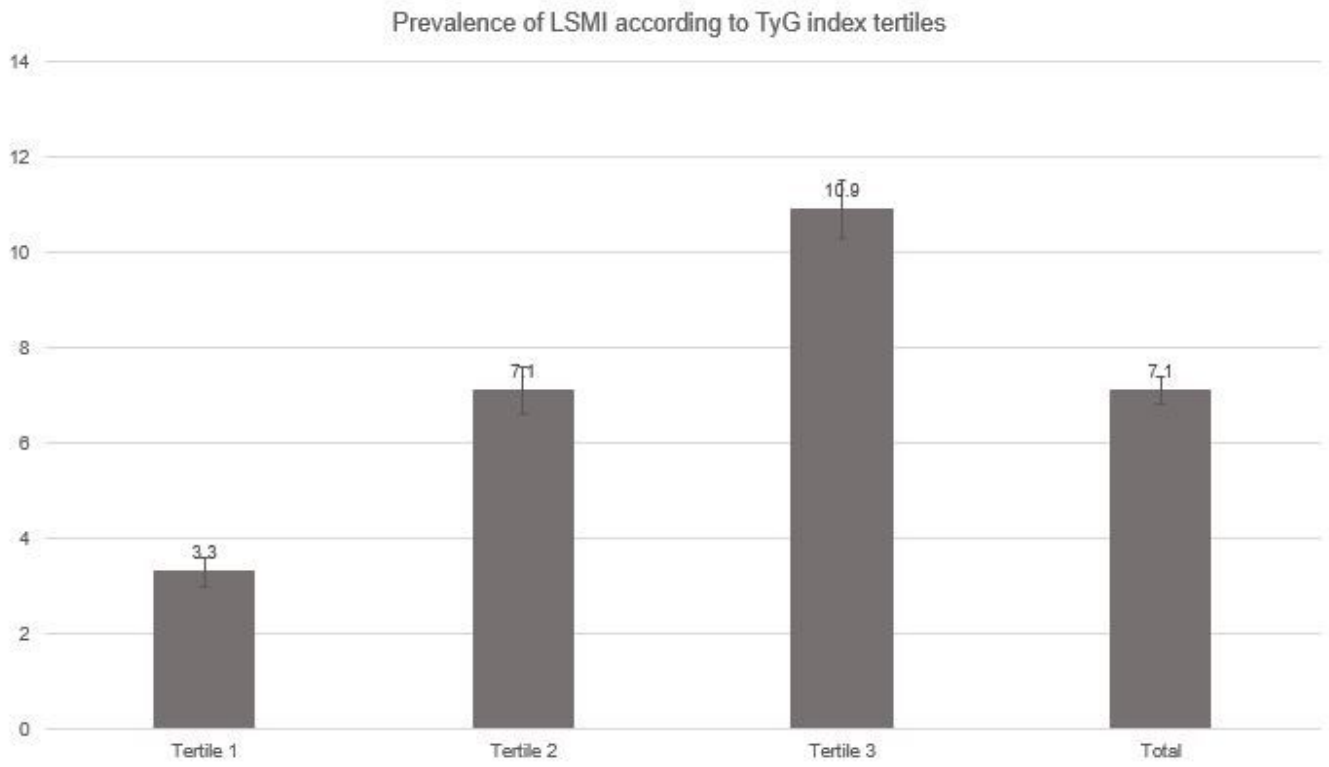

Figure 2

Prevalence of LSMI according to TyG index tertiles