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Original Research

Skeletal Muscle Mass is Associated with HDL Cholesterol Levels and the Ratio of LDL to HDL Cholesterol in Young Men: A Pilot Study

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Abstract

Background: It is unclear whether greater skeletal muscle mass is beneficial for improving cardiometabolic health in young individuals. Our purpose was to investigate the association between skeletal muscle mass and cardiometabolic risk factors in young males. **Methods**: Data were collected from thirty-seven young males (23.2 ± 0.3 years). Participants were categorized based on skeletal muscle mass (skeletal muscle index-percentile score, SMI-PS) assessed by bioelectrical impedance analysis. They were divided into two group: standard skeletal muscle mass group (SMG, n = 17, SMI-PS = 102.2 ± 1.0%), high skeletal muscle mass group (HMG, n = 20, SMI-PS = 120.5 ± 1.8%). Arterial stiffness assessed by brachial-ankle pulse wave velocity (baPWV) and blood parameters including high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), total cholesterol (TC), triglycerides (TG), fasting glucose (FG) and hemoglobin A1c (HbA1c) were assessed. **Results**: The level of HDL-C in HMG was significantly higher compared to SMG ($p < 0.001$), whereas the ratio of LDL-C to HDL-C in HMG was significantly lower compared to SMG ($p < 0.001$). However, no changes in baPWV, TC, LDL-C, TG, FG, and HbA1c were found between groups. Interestingly, there was a positive correlation between SMI-PS and HDL-C ($r = 0.469$, $p = 0.003$), whereas there was a negative correlation between SMI-PS and LDL-C/HDL-C ($r = –0.38$, $p = 0.02$). **Conclusions**: This study suggests that an increase in skeletal muscle mass may have an additive benefit on improving lipid components through the increased HDL-C level and decreased the ratio of LDL-C to HDL-C in young men.

Keywords: skeletal muscle; cardiometabolic risk factor; HDL cholesterol; LDL cholesterol; arterial stiffness

1. Introduction

Skeletal muscles are tissues that account for about 30–40% of the human body and 50–75% of whole-body proteins [1,2]. Skeletal muscles are affected by factors such as the nutritional status, hormone balance, diseases, and exercise, and have the characteristic of plasticity that the skeletal muscle mass changes according to the balance between protein synthesis and degradation [2]. According to a study conducted by Lexell *et al*. [3] the skeletal muscle mass reaches its maximum at the age of approximately 24 years, and decreases thereafter due to aging, which causes the atrophy and reduction of mainly type II muscle fibers. The reduction of skeletal muscle mass occurs gradually from the age of 25 years to the age of 50 years (approximately 10%), and continues conspicuously thereafter [3]. The age-related loss of skeletal muscle mass can have negative effects on cardiometabolic disorders including insulin resistance, dyslipidemia, type 2 diabetes, and cardiovascular diseases [4–7]. In addition, given the Coronary Artery Risk Development in Young Adults study showed that early adulthood risk factors, including dyslipidemia, are associated with increased coronary atherosclerosis 2 decades later in middle age [8,9]. This finding suggests that managing coronary atherosclerotic risk factors from a young age may be a proactive prevention strategy which can help reduce cardiovascular diseases in the future.

Exercise and nutritional interventions to preserve or increase the skeletal muscle mass are the methods to prevent cardiometabolic diseases, but what benefits the increase in the skeletal muscle mass actually provides in relation to cardiometabolic risk factors such as lipids components and arterial stiffness in young males has not yet been clearly elucidated. Skeletal muscle hypertrophy occurs in response to stimuli such as exercise, endogenous anabolic hormone responses, and proper nutrition when muscle protein synthesis exceeds muscle protein breakdown in skeletal muscles [10]. Increasing the skeletal muscle mass through resistance exercise is known to prevent sarcopenia, the American College of Sports Medicine recommends resistance exercise to improve the conditions of type 2 diabetes patients and improve cardiovascular functions because the increase in the skeletal muscle mass through resistance exercise is associated with effective glucose homeostasis independent of the intrinsic ability of the skeletal muscles to respond to insulin [11,12]. Therefore, the increase in skeletal muscle mass induced by resistance exercise is considered to improve cardiometabolic health including insulin resistance and dyslipidemia [13]. In addition, a study conducted by

Ochi *et al.* [14] showed that a greater cross-sectional area of the thigh muscle in middle-aged men was associated with a lower brachial-ankle pulse wave velocity (baPWV), suggesting increases in the skeletal muscle mass may also be related to arterial compliance. However, there was little research on the relationship between skeletal muscle mass and baPWV in young men.

On reviewing previous studies, it can be seen that most previous studies related to the skeletal muscle mass and cardiometabolic diseases were conducted with middle-aged or elderly population, and divided the participants into two groups (a group with the skeletal muscle mass within the normal range vs. a group with relatively more symptoms of sarcopenia) in the studies [15–17]. Because studies on the benefits of young individuals with high quantities skeletal muscle mass are insufficient, this study was conducted to explore the relationship between skeletal muscle mass and cardiometabolic risk factors in young males. The purpose this study was to investigate whether greater skeletal muscle mass from a young age who reached an age of approximately maximum skeletal muscle mass may have a positive effect on cardiometabolic risk factors.

2. Materials and Methods

2.1 Participants

The participants of this study were 52 young university males aged between 20 and 27 years recruited from among those who showed a voluntary intention to participate in the study. Participants were nonsmokers and determined healthy through a questionnaire contained self-report of health history. Exclusion criteria were set as those whose skeletal muscle mass is below the standard (90%), smokers or those who quit smoking within 5 years, and those who clinically correspond to patients with any of musculoskeletal disorders, kidney diseases, hyperthyroidism, cardiometabolic diseases including hypertension, metabolic syndrome, and type 2 diabetes. Among the 52 participants, 15 were excluded according to the exclusion criteria, and the study was conducted with 37 active (more than or equal to three sessions per week) men in their 20s clinically without any certain disease. Experimental details including the purpose and procedure of the study and potential risks involved in the study were explained to all participants and they voluntarily signed a written consent to participate in the study.

2.2 Study Design

This study calculated the sample size using G*Power version 3.1.9.4 program (Düsseldorf University, Düsseldorf, Germany) based on the results of a previously published study [18]. The total sample size for correlation analysis (two-tail, correlation ρ H1: 0.52, α error: 0.05, power: 0.8) was calculated to be at least 26 participants. Each study participant was instructed to restrict strenuous physical activities and drinking alcohol for 24 hours before the visit, and maintained the fasted state for at least 10 hours before participating in the measurements of blood parameters and arterial stiffness. Each participant arrived at the laboratory where temperature and humidity were maintained under stable condition in the morning (between 09:00 AM and 11:00 AM). Height, body composition, resting blood pressure, peripheral arterial stiffness, levels of lipid and glucose profiles in circulation were measured in order. The overall study procedure was shown in Fig. 1.

2.3 Anthropometric Measurement and Group Classification

The height (cm) was measured using an extensometer (Samhwa, Seoul, South Korea), and body composition was measured using a body composition analyzer (Inbody 720, Biospace, Seoul, South Korea) that utilizes bioelectrical impedance analysis (BIA). During the measurement, each participant wore a short sleeved-shirt and shorts, removed metal materials, and stood on a support with their bare hands and feet kept in contact with a total of eight electrodes (two on the palms, two on the thumbs, two on the toes, and two on the heels). The study participants were measured while they were holding the electrode handle and their arms were spread out about 15° sidewards. The height (cm), skeletal muscle mass (kg), body fat mass (kg), body fat percentage (%), and visceral fat area (cm^2) obtained through height measurement and body composition analysis were used in this study.

The skeletal muscle mass of each participant was determined by a body composition analyzer and the data was calculated and expressed as the skeletal muscle mass index to $height^2$ ratio (SMI-H), the skeletal muscle mass index to weight ratio $\times$ 100 (SMI-W), the skeletal muscle mass index to visceral fat area ratio (SMI-V), and the skeletal muscle mass index-percentile score (SMI-PS), respectively. Of those indexes, the SMI-PS enables classifying the range below the standard (less than 90%), the standard range (90–110%), and the range above the standard (exceeding 110%) through the body composition analysis result sheets [19]. Therefore, the study participants were finally classified using the SMI-PS into a standard skeletal muscle mass group (SMG) with the SMI-PS in the standard range (90–110%) and a high skeletal muscle mass group (HMG) with the SMI-PS exceeding the standard (exceeding 110%).

The formula to obtain the SMI-PS was as follows; SMI-PS (%) = (study participant's skeletal muscle mass/median value of skeletal muscle mass in the normal range) $\times$ 100. The reference values for classification of study participants were as shown in Table 1.

2.4 Blood Pressure and Arterial Stiffness

After each participant took a rest on the experimental bed for at least 10 min, systolic and diastolic blood pressure at rest were measured using Accuniq BP850 (Jawon Medical, Seoul, South Korea). The systolic and diastolic

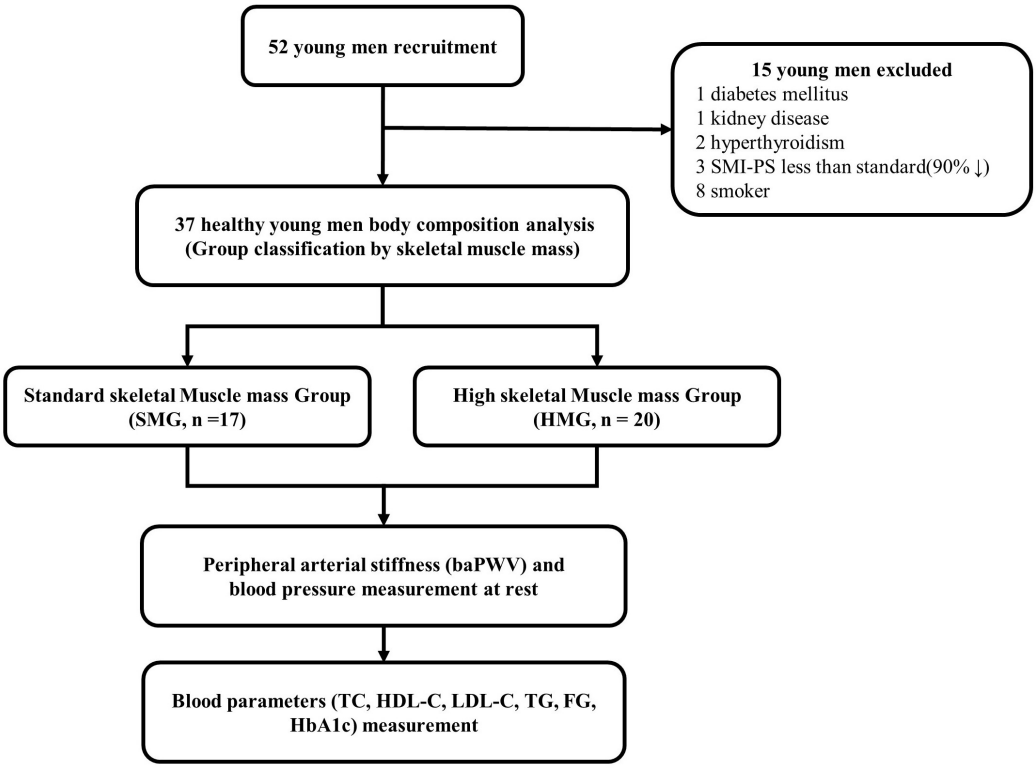

Fig. 1. Schematic flow chart.

Table 1. Study criteria for the classification of standard and high skeletal muscle group.

Variables	SMG (n = 17)	HMG (n = 20)	*p*-value
SMI (kg)	32.3 ± 0.5	37.7 ± 0.9	<0.001***
SMI-H (kg/m²)	10.7 ± 0.1	12.6 ± 0.2	<0.001***
SMI-PS (%)	102.2 ± 1.0	120.5 ± 1.8	<0.001***
SMI-V (kg/cm²)	0.7 ± 0.1	0.9 ± 0.1	0.051
SMI-W (%)	44.9 ± 0.9	48.0 ± 0.6	0.006**

Values are presented as mean ± standard error. HMG, high skeletal muscle mass group; SMG, standard skeletal muscle mass group; SMI, skeletal muscle mass index (kg); SMI-H, skeletal muscle mass index to height^2 ratio (kg/m^2); SMI-PS, skeletal muscle mass index percentile score; SMI-V, skeletal muscle mass index to visceral fat area ratio (kg/cm^2); SMI-W, skeletal muscle mass index to weight ratio × 100. $^{**}p < 0.01$, $^{***}p < 0.001$ compared between groups.

blood pressures were measured and used with average values of both arms. Peripheral arterial stiffness was assessed as previously described in detail [20,21]. In brief, the arterial stiffness was measured non-invasively using the Omron Pulse Waveform Analyzer VP-1000 plus (Omron, Kyoto, Japan) through the baPWV. The participants wrapped cuffs embedded with a sensor on their both upper arms and ankles, and waveforms were collected from the extremities. Using the built-in formula, the value was obtained by automatically calculating the distance and pulse wave transit time between the extremities arteries based on the height.

2.5 Blood Analysis

In fasted state, 35 μL of whole blood was collected from index finger of each participant. Blood lipid including total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), triglycerides (TG), and fasting glucose (FG) were measured using the Cholestech LDX analyzer (Alere, Oslo, Norway) [21]. In addition, 1.5 μL of whole blood was collected from index finger and glycated hemoglobin (hemoglobin A1c, HbA1c) was measured using Afinion AS 100 (Alere, Oslo, Norway) according to the manufacturer's protocol [21].

2.6 Statistics

Statistical analysis was analyzed using the GraphPad Prism version 8 software program (GraphPad Software, La Jolla, CA, USA). Data on variables were showed as mean and standard error (mean ± SE), and normality of distribution for variables was assessed using the Shapiro-Wilk test. Independent *t*-tests were used for comparison between groups according to skeletal muscle mass. The Mann-Whitney U-test was used in the case of variables that do not follow the normality. The correlations between the skeletal muscle mass and cardiometabolic risk factors were analyzed through Pearson's correlation analysis, and in the case of variables not following the normality, Spearman's correlation analysis was used. All statistical significance levels were set to $p < 0.05$.

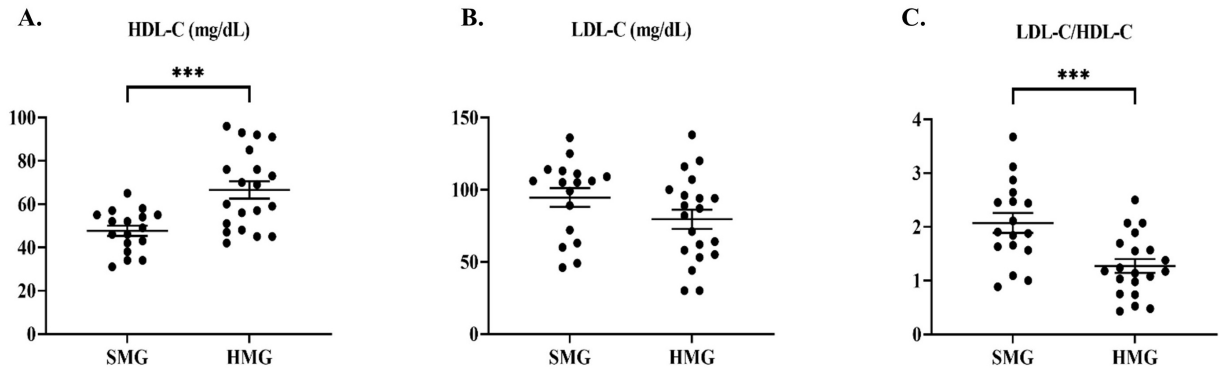

Fig. 2. Comparison of blood parameters between SMG and HMG. Comparison of HDL-C (A), LDL-C (B), and LDL-C/HDL-C (C) between groups. SMG, standard skeletal muscle mass group; HMG, high skeletal muscle mass group; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; LDL-C/HDL-C, LDL-C to HDL-C ratio. ***$p < 0.001$ compared between groups.

3. Results

3.1 Comparison of Basic Clinical Characteristics between the Groups

The study participants were divided into an HMG (n = 20) and a SMG (n = 17) based on SMI-PS. Table 2 showed the results of comparison of anthropometric data, blood pressure, and peripheral arterial stiffness assessed by baPWV between the groups. The HMG had significantly higher body weight ($p = 0.024$), BMI ($p = 0.002$), thigh circumference ($p = 0.002$), and basal metabolic rate ($p < 0.001$) than the SMG. On the other hand, the body fat percentage ($p = 0.018$) was significantly higher in the SMG. Age, height, body fat mass, visceral fat area, waist-hip circumference ratio, baPWV, systolic and diastolic blood pressure were not significantly different between the groups.

Table 2. Basic clinical characteristics of study participants.

Variables	SMG (n = 17)	HMG (n = 20)	*p*-value
Age (years)	22.9 ± 0.5	23.5 ± 0.4	0.370
Height (cm)	173.8 ± 1.1	172.9 ± 1.1	0.577
Weight (kg)	72.5 ± 1.9	78.5 ± 1.7	0.024*
BMI (kg/m^2)	23.9 ± 0.6	26.2 ± 0.4	0.002**
Body fat mass (kg)	15.5 ± 1.5	12.9 ± 0.9	0.137
Body fat (%)	20.8 ± 1.6	16.4 ± 1.0	0.018*
Visceral fat area (cm^2)	61.0 ± 6.8	50.3 ± 4.3	0.178
Thigh circumference (cm)	55.3 ± 0.7	58.9 ± 0.8	0.002**
WHR	0.86 ± 0.14	0.83 ± 0.01	0.082
BMR (kcal)	1599.7 ± 17.4	1777.5 ± 31.8	<0.001***
baPWV (cm/s)	1158.1 ± 31.0	1164.3 ± 23.9	0.874
SBP (mmHg)	118.8 ± 1.9	115.7 ± 2.2	0.304
DBP (mmHg)	66.2 ± 1.6	62.8 ± 1.8	0.165

Values are presented as mean ± standard error. SMG, standard skeletal muscle mass group; HMG, high skeletal muscle mass group; Age, Height, Weight; BMI, body mass index; Visceral fat area; WHR, waist to hip ratio; BMR, basal metabolic rate; baPWV, brachial-ankle pulse wave velocity; SBP, systolic blood pressure; DBP, diastolic blood pressure. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ compared between groups.

3.2 Comparison of Blood Parameters between the Groups

The comparison of blood parameters between the groups were showed in Fig. 2. There were no significant differences in the values of TC, TG, FG, HbA1c (Data not shown) and LDL-C (Fig. 2B) between the groups. Interestingly, HDL-C ($p < 0.001$, Fig. 2A) in the HMG was significantly higher than that in the SMG, whereas LDL-C/HDL-C ($p < 0.001$, Fig. 2C), which shows the ratio of LDL-C to HDL-C, in the HMG was shown to be significantly lower than that in the SMG.

3.3 Correlation between Skeletal Muscle Mass and Cardiometabolic Risk Factors

The correlations between the SMI-PS, an indicator of skeletal muscle mass, and cardiometabolic risk factors including blood parameters and arterial stiffness were analyzed with the data on a total of 37 participants. The result of the correlations showed a significant positive correlation between the SMI-PS and HDL-C ($r = 0.469$, $p = 0.003$, Fig. 3A), a significant negative correlation between the SMI-PS and LDL-C/HDL-C ($r = –0.38$, $p = 0.02$, Fig. 3C). However, there was no correlation between the SMI-PS and LDL-C ($r = –0.083$, $p = 0.627$, Fig. 3B), between the SMI-PS and the rest of the blood variables (TC, LDL-C, TG, FG, HbA1c) (Table 3), or between the SMI-PS and baPWV ($r = 0.011$, $p = 0.951$, Fig. 3D). In addition, the correlations between the SMI-H, SMI-W, or SMI-V and cardiometabolic risk factors were analyzed and, as with the results of analysis of the correlations between the SMI-PS and cardiometabolic risk factors, the results showed positive correlations between the SMI-H, SMI-W, or SMI-V and HDL-C, negative correlations between the SMI-H, SMI-W, or SMI-V and LDL-C/HDL-C. However, no significant correlation between the SMI-H, SMI-W, or

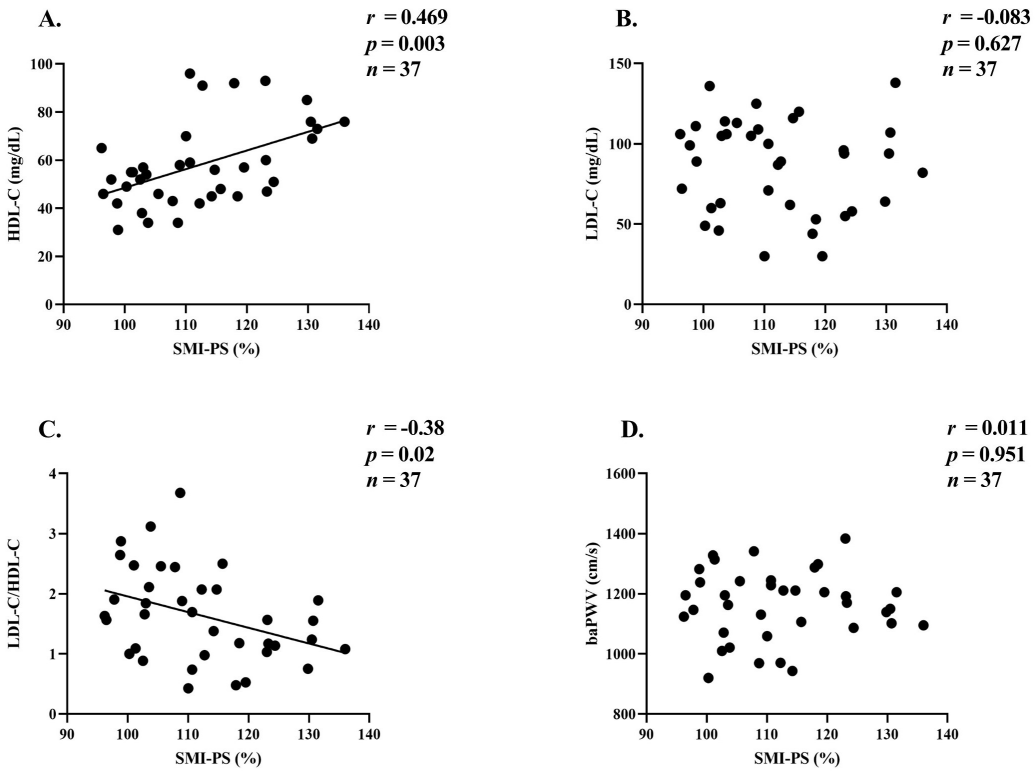

Fig. 3. Relationship between SMI-PS and HDL-C (A), LDL-C (B), LDL-C/HDL-C (C), and baPWV (D). SMI-PS, skeletal muscle mass index-percentile score; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; LDL-C/HDL-C, LDL-C to HDL-C ratio; baPWV, brachial-ankle pulse wave velocity.

SMI-V and the rest of the blood variables (TC, LDL-C, TG, FG, HbA1c) or baPWV (Table 3).

4. Discussion

This study aimed to investigate whether greater skeletal muscle mass is beneficial for improving cardiometabolic health, and the association between skeletal muscle mass and cardiometabolic risk factors in young males. According to the results of the comparison and analysis, the HMG had significantly higher HDL-C and lower the ratio of LDL-C/HDL-C compared to the SMG. In addition, the correlation analysis showed a positive correlation between the skeletal muscle mass and HDL-C, and a negative correlation between the skeletal muscle mass and LDL-C/HDL-C. Other variables including TC, LDL-C, TG, FG, HbA1c and baPWV did not show any difference between the groups or any correlation with the skeletal muscle mass.

LDL-C and HDL-C have been reported to be independent risk factors for coronary artery diseases [22]. When the level of LDL-C in the blood has risen, LDL is modified including being oxidized [23]. The oxidized LDL-C forms foam cells due to vascular endothelial cell damage and lipid accumulation in macrophages to cause fatty streak leading to the formation of fibrous plaques that impede blood flow in blood vessels, thereby becoming a major cause of atherosclerosis [24]. On the other hand, HDL-C inhibits the oxidation of LDL-C, removes cholesterol from blood vessel walls by transporting cholesterol from foam cells to the liver, and has anti-atherosclerotic and anti-thrombotic effects [23], thereby may play an important role in the regulation of vascular homeostasis [25,26]. For these reasons, the ratio of LDL-C/HDL-C has been reported to be an important indicator for predicting coronary artery disease [27–29], and both high LDL-C and low HDL-C levels are known to increase the risk of occurrence of coronary artery and cardiovascular diseases [22,30–32]. Sarcopenia may increase the risk of cardiometabolic diseases, including dyslipidemia, type 2 diabetes and cardiovascular disease [5–7]. In this study, although the participants were 20s without sarcopenia, the results showed differences in HDL-C and LDL-C/HDL-C between groups. In addition, given that the results of analysis showed a lower LDL-C/HDL-C level and a higher HDL-C level in the HMG compared to the SMG despite that the HDL-C and LDL-C levels of SMG are within the normal range. Therefore, greater skeletal muscle mass may potentially benefit the improving lipid components in young male individuals.

With regard to previous studies that examined differences in cardiometabolic risk factors according to skeletal muscle mass, Furushima *et al.* [33] showed no differ-

Table 3. Correlation analysis between SMI-H, SMI-PS, SMI-V, SMI-W and risk factor for cardiometabolic disease.

Variables	SMI-H		SMI-PS		SMI-V		SMI-W	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
TC	0.294	0.078	0.301	0.070	0.174	0.304	0.241	0.150
HDL-C	0.464	0.004**	0.469	0.003**	0.564	<0.001***	0.575	<0.001***
LDL-C	–0.084	0.622	–0.083	0.627	–0.203	0.228	–0.195	0.248
TG	0.192	0.254	0.202	0.231	0.099	0.559	0.109	0.520
FG	0.156	0.355	0.163	0.336	–0.191	0.257	–0.207	0.220
LDL-C/HDL-C	–0.376	0.022*	–0.380	0.020*	–0.446	0.006**	–0.519	0.001**
HbA1c	0.026	0.878	0.007	0.965	–0.058	0.743	–0.033	0.846
baPWV	–0.002	0.992	0.011	0.951	0.075	0.659	0.153	0.366
BMI	0.675	<0.001***	0.672	<0.001***	–0.377	0.021*	–0.331	0.045*

Correlation coefficients (r) and p values were calculated using the Pearson's correlation analysis, and in the case of variables not following the normality, Spearman's correlation analysis was used. baPWV, brachial-ankle pulse wave velocity; BMI, body mass index; FG, fasting glucose; HDL-C, high density lipoprotein cholesterol; HbA1c, hemoglobin A1c; LDL-C, low density lipoprotein cholesterol; LDL-C/HDL-C, LDL-C to HDL-C ratio; TC, total cholesterol; TG, triglyceridel; SMI-H, skeletal muscle mass index to height^2 ratio (kg/m^2); SMI-PS, skeletal muscle mass index percentile score; SMI-V, skeletal muscle mass index to visceral fat area ratio (kg/cm^2); SMI-W, skeletal muscle mass index to weight ratio $\times$ 100. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ correlation analysis between skeletal muscle mass and cardiometabolic risk factors.

ence in the variables HDL-C, TG, TG/HDL-C, and HbA1c between the group with normal skeletal muscle mass and the group with sarcopenia among adults aged 41–90 years. On the other hand, in a study conducted by Hwang *et al.* [13] the group with normal skeletal muscle mass had significantly higher HDL-C and significantly lower TC, LDL-C, and TG compared to the sarcopenia group. With regard to previous studies that examined the correlations between skeletal muscle mass and cardiometabolic risk factors, in a study conducted with 40–75 years-old patients with type 2 diabetes, showed no correlation between skeletal muscle mass to visceral fat area ratio and LDL-C, HDL-C, and TG [34]. However, in another study conducted with people aged at least 40 years, a positive correlation appeared between skeletal muscle mass and HDL-C, and negative correlations appeared between skeletal muscle mass and TG, LDL-C, and the homeostasis model assessment of insulin resistance (HOMA-IR), an indicator of insulin resistance [17].

Some of the previous studies are consistent with this study, and some are not. In order to understand the additive benefits of having a greater skeletal muscle mass, this study was conducted on adults in their 20s who reached an age of approximately maximum skeletal muscle mass. In a previous study conducted by Matsumoto *et al.* [35] with youths aged 16–26 years, HDL-C was significantly higher in the group with relatively high quantities skeletal muscle masses compared to the control group, and LDL-C showed only a tendency between the groups without showing any significant difference. The significant difference in HDL-C is consistent with the results of this study.

The high level of circulating HDL-C can be beneficial in the prevention and management of cardiovascular disease, eg, atherosclerosis and coronary artery disease [23,36]. Although the mechanisms for chronic inflammation in various diseases and sarcopenia are still unclear [4], HDL-C and apolipoprotein A-I (ApoA-I) have anti-inflammatory properties [37,38]. For example, Maarit *et al.* [32] have shown that ApoA-I, a component of HDL-C, can improve mitochondrial function and cellular respiration of skeletal muscle cells, thereby directly increasing glucose utilization. In this regard, ApoA-I was shown to be an essential element in regulating glucose homeostasis because it regulated glucose transport independent of insulin action [32]. Since intracellular glucose metabolism plays a pivotal role in insulin resistance and etiological causes of diabetes, raising HDL-C levels may be effective in the prevention and management of insulin resistance, type 2 diabetes, and cardiovascular diseases [32]. In fact, it has been reported that an elevation of the HDL-C level by 1 mg/dL was associated with a 3–4% reduction in cardiovascular diseases [36,39]. Combining this study with previous studies, increasing skeletal muscle mass may partially play a positive role in lipoprotein metabolism suggesting that the skeletal muscle mass should be maintained or increased from a young age. In addition, a longitudinal study should be conducted with the young adults who had greater skeletal muscle mass to find out what additive benefit on a cardiometabolic risk factor when they reach middle-aged or elderly.

The mechanism of the increase in HDL-C is not clear, but some of the potential mechanisms may be considered. A number of previous studies have shown that aerobic exercise increased the level of circulating HDL-C [40]. Aerobic exercise can activate the expression of AMP-activated protein kinase, peroxisome proliferator-activated receptor gamma coactivator 1-alpha, and Sirtuin 1 proteins which are regulators of the transcriptional activity of peroxisome

proliferator-activated receptor alpha (PPARα) in skeletal muscles [41,42]. The activation of PPARα may increase ApoA-I production, results in high HDL-C levels [31]. Although some previous studies showed that resistance exercise, which predominantly induces increases in skeletal muscle mass, increased HDL-C [43], the mechanisms involved have not been clearly elucidated. Increases in HDL-C through resistance exercise which induces greater skeletal muscle mass may partially share the mechanisms to the effect of aerobic exercise on high HDL-C levels.

Arterial stiffness is a main independent risk factor that can predict cardiovascular diseases, especially in adult men [44,45]. The greater cross-sectional area of the thigh muscle in middle-aged men was associated with lower arterial stiffness [14]. Even in young adults, a lower dilatory capacity of the brachial artery may increase the number of cardiovascular risk factors [46]. These findings suggest that managing blood vessel function and skeletal muscle mass from a young age may be a proactive strategy to prevent future cardiovascular diseases. BaPWV, which is one of methods to measure arterial stiffness, has a popular method for non-invasive measurement [47]. According to previous studies, a negative correlation between the skeletal muscle mass and baPWV was found in many cases [33,34], but no difference in baPWV between the groups showed in this study. The difference may be considered to be attributable to the fact that participants of this study were young and healthy, unlike the majority of previous studies that were conducted with participants aged at least 40 years or with cardiovascular risk factors such as diabetes [33,34]. Hereafter, further studies should be conducted to confirm our finding in the middle-aged or elderly population. In addition, additional research is necessary to confirm the role of skeletal muscle, and the advantages of having greater skeletal muscle mass on vascular function for individuals with various diseases including type 2 diabetes, dyslipidemia, hypertension and metabolic syndrome.

This study has several limitations. First, this study was the lack of information on participant's dietary habits such as the Mediterranean diet which has shown to improve cardiometabolic risk factors [48]. Therefore, in future studies, a study design with adequate dietary control is required. Second, the body weight and BMI between groups could not be controlled in this study. Compared to the SMG, the HMG had significantly higher body weights and BMI, and the mean BMI of the HMG corresponded to obesity. However, the results of this study suggest that greater skeletal muscle mass has advantages rather than the risk of cardiometabolic diseases even when the BMI is high. In addition, recently, a study conducted by Kim *et al*. [49] with overweight and obese participants aged 12–18 years showed that greater skeletal muscle mass plays a potential protective role against cardiometabolic risk factors. Therefore, the potential factors of the obesity paradox may be considered to be greater skeletal muscle mass. Future studies are needed with individuals with normal weight and obesity while controlling the BMI of the groups to examine what benefits high quantities skeletal muscle mass can provide against cardiometabolic risk factors compared to low quantities skeletal muscle mass.

5. Conclusions

In conclusion, this study was conducted to investigate the difference and correlation of cardiometabolic risk factors according to skeletal muscle mass in young adults. According to the results of the study, the HMG had significantly lower LDL-C/HDL-C and higher HDL-C compared to SMG. In addition, skeletal muscle mass was negatively correlated with LDL-C/HDL-C and positively correlated with HDL-C. This suggests that an increase in the skeletal muscle mass may have an additive benefit through the improvement of lipid components, and that the skeletal muscle mass should be maintained or increased from a young age.

Author Contributions

MJ, YK and SL designed the research study. MJ and YK performed experiments and analyzed the data. MJ and YK wrote and prepared the original draft. SL reviewed and edited the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics Approval and Consent to Participate

This study was approved by the procedure of the Institutional Review Board at Incheon National University (permission# 7007971-201904-001-10).

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Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

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