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Needs thigh and calf muscle exercise for better glucose control based on Bioelectrical Impedance Analysis

Sihyung Park
Inje University Haeundae Paik Hospital
Chang Min Heo
Inje University Haeundae Paik Hospital
Bong Soo Park
Inje University Haeundae Paik Hospital
Jung Hae Ko
arrioph@hanmail.net

Inje University Haeundae Paik Hospital

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Abstract

Objective

Patients with diabetes mellitus (DM) spent hard time to control disease during the COVID 19 quarantine measures. This study evaluated bioelectrical impedance analysis (BIA) variables to identify modifiable factors for improving insulin resistance (IR) in early type 2 DM.

Methods

Eighty-two patients who diagnosed the type 2 DM within 5 years were enrolled. The participants were evaluated for body composition using BIA, alongside biochemical profiles and IR measured by the homeostasis model assessment 2 (HOMA-IR).

Results

Patients were categorized into tertiles based on HOMA-IR values (≤ 1.6, 1.6–2.3, ≥ 2.3). Patients in the highest IR tertile exhibited significantly higher body mass index, fat mass, and circumferences of the waist, neck, and arm. Conversely, the ratios of skeletal and leg muscle mass to fat mass, as well as thigh and calf circumference to waist circumference, were highest in the lowest IR tertile, indicating a strong negative correlation between lower-limb muscle proportion and IR.

Conclusion

These findings demonstrate that while weight reduction is critical, increasing muscle mass (particularly in the lower extremities) is equally essential for improving IR. Strength exercises targeting lower-limb muscles provide a vital strategy for optimal glucose control, highlighting BIA's clinical utility in tailoring lifestyle interventions.

Introduction

The prevalence of obesity is increasing globally, and it is widely recognized as a complex multifactorial chronic disease.[1] Type 2 diabetes mellitus (DM) is a representative metabolic disorder closely associated with this obesity epidemic. While pharmacological treatments are fundamental in T2DM care, managing such chronic diseases cannot rely on medication alone; continuous lifestyle modifications, particularly weight loss and physical activity, are essential for optimal glucose control and delaying disease progression. A study had reported that an intensive program for weight loss and its maintenance had been reported its benefits for type 2 DM.[2] Moreover, the 2020 position statements of the American Diabetes Association have indicated that there is strong and consistent evidence that

obesity management can delay the progression to diabetes mellitus and give some beneficial effects on treatment.[3] Recently, however, global public health crises such as the COVID-19 pandemic and subsequent quarantine measures have drastically altered daily routines. These unforeseen circumstances have severely restricted outdoor activities and hindered regular hospital visits. This unprecedented environmental shift led to a significant decline in overall physical activity, particularly aerobic exercises, making it increasingly difficult for patients to manage their body weight and maintain steady glucose levels. Under such restrictive circumstances, identifying alternative, modifiable lifestyle factors, particularly those that can be managed through indoor resistance exercises, has become increasingly important.

To discover these modifiable factors, precise assessment of a patient's body composition is required. Although Body Mass Index (BMI) and waist circumference are currently the most common methods to assess obesity, they have significant limitations because they cannot evaluate exact body composition, such as the crucial balance between skeletal muscle and fat mass.[4] Conversely, bioelectrical impedance analysis (BIA) is a ubiquitous, non-invasive method that can accurately measure body water, fat-free mass, and regional body fat. BIA has been widely validated and used in large clinical trials, including the Diabetes Control and Complications Trial.[5]

Therefore, the aim of this study was to evaluate comprehensive BIA variables to identify valuable, modifiable body composition factors—such as regional muscle mass—that can guide effective type 2 DM management. By doing so, we sought to determine the best strategies for glucose control when traditional outdoor aerobic exercises are limited.

Results

Clinical and biochemical characteristics of the participants

A total of 82 individuals (44 women and 38 men) were analyzed. The mean age of the participants was 41.5 ± 9.5 years, with an average diabetes duration of 1.89 years. The mean body weight was 80.1 ± 17.9 kg, mean HbA1c was 7.3 ± 1.6%, and mean HOMA-IR was 2.36 ± 1.25. Detailed baseline clinical and biochemical characteristics are presented in Tables 1.

Table 1
Baseline clinical and biochemical characteristics of the study populations.

Age (year)	**Male (38)**	**Female (44)**	**Total (82)**	**p**
	40.16 ± 7.3	**42.68 ± 11.1**	**41.5 ± 9.57**	**0.22**
Duration of DM (year)	1.41 ± 1.99	2.31 ± 3.6	1.89 ± 2.99	0.17
Body weight (kg)*	88.67 ± 17.61	72.79 ± 14.86	80.15 ± 17.96	< 0.01
Body mass index (kg/m^2)	29.15 ± 5.43	27.75 ± 5.06	28.4 ± 5.25	0.23
HOMA-IR	2.64 ± 1.6	2.11 ± 0.78	2.36 ± 1.25	0.68
HOMA-IS	50.39 ± 26.9	55.19 ± 24.4	52.97 ± 25.54	0.40
HOMA-beta	80.19 ± 48.47	77.57 ± 31.63	78.78 ± 40.08	0.77
HbA1C (%)	7.74 ± 2	6.91 ± 1.1	7.3 ± 1.63	0.27
LDL-C (mg/dL)	117.17 ± 39.52	116.39 ± 45.53	116.75 ± 42.59	0.93
HDL-C (mg/dL)*	45.43 ± 8.8	52.25 ± 14.2	49.09 ± 12.43	0.01
Triglyceride (mg/dL)	204.72 ± 213.71	149.08 ± 84.87	174.87 ± 159.58	0.13
Relative fat mass*	29.34 ± 5.06	40.47 ± 4.70	35.31 ± 7.39	< 0.01
Body fat percentage (%)*	29.97 ± 7.63	37.31 ± 6.54	33.91 ± 7.92	< 0.01
Fat mass (kg)*	27.67 ± 11.95	27.84 ± 9.75	27.76 ± 10.75	< 0.01
Muscle mass (kg)*	57.59 ± 7.13	42.31 ± 6.23	49.39 ± 10.13	< 0.01
Waist circumference*	102.71 ± 15.82	93.32 ± 13.38	97.67 ± 15.22	< 0.01
Abdominal Fat depth (cm)	1.47 ± 0.51	1.51 ± 0.45	1.49 ± 0.48	0.72
Leg circumference (cm)*	57.18 ± 5.07	54.66 ± 5.62	55.83 ± 5.49	0.03
*) $p < 0.05$				

Inter-relationship between HOMA-IR tertile and BIA variables

Participants were stratified into tertiles based on their HOMA-IR values: 1st tertile (≤ 1.6, n = 22), 2nd tertile (1.6–2.3, n = 33), and 3rd tertile (≥ 2.3, n = 27). As shown in Table 2, parameters including fat mass, muscle mass, skeletal muscle mass, free fat mass, BMI, HbA1c, and circumferences of the neck, arm, and waist were highest in the 3rd tertile group. Conversely, the ratios of skeletal muscle to fat mass, leg muscle to fat mass, and thigh/calf circumference to waist circumference were highest in the 1st tertile, indicating a strong inverse relationship between these lower-limb muscle indices and insulin resistance (Fig. 1).

Table 2
Comparison of body composition and biochemical variables according to HOMA-IR tertiles.

HOMA-IR (tertile)	**≤ 1.6**	**1.6 ~ 2.5**	**≥ 2.5**	**P**
N	22	33	27	
HbA1C (%)	6.5 ± 1.29	7.2 ± 1.5	*8.05 ± 1.75	< 0.01
HOMA-IR	1.23 ± 0.26	*2.01 ± 0.22	*‡ 3.69 ± 1.32	< 0.01
HOMA-beta	67.4 ± 34.1	78.66 ± 26.84	88.20 ± 54.55	0.19
LDL-C (mg/dL)	104.14 ± 27.2	125.03 ± 54.41	116.91 ± 34.47	0.20
Triglyceride (mg/dL)	99.14 ± 68.04	144.83 ± 62.24	*‡273.28 ± 234.04	< 0.01
Glucose (fasting, mg/dL)	120.45 ± 22.55	131.55 ± 28.38	*170.2 ± 48.6	< 0.01
Body weight (kg)	62.22 ± 12.75	*78.54 ± 12.21	*‡94.28 ± 17.04	< 0.00
Body mass index (kg/m^2)	23.62 ± 3.2	*28.36 ± 3.4	*‡32.34 ± 5.2	< 0.01
Fat mass (kg)	18.13 ± 6.51	*28.58 ± 7.06	*‡34.61 ± 11.69	< 0.01
Body fat percentage (%)	27.5 ± 6.94	*36.31 ± 6.35	*36.2 ± 7.72	< 0.01
Relative fat mass	29.87 ± 6.89	*37.82 ± 6.18	*36.68 ± 7.06	< 0.01
Muscle mass (kg)	44.35 ± 8.58	47.09 ± 8.55	*‡56.31 ± 9.6	< 0.01
Fat free mass (kg)	47.08 ± 9.03	49.96 ± 9.03	*‡59.66 ± 10.09	< 0.01
Skeletal muscle (kg)	25.92 ± 5.49	27.59 ± 5.43	*‡33.57 ± 6.14	< 0.01
Arm circumference (cm)	29.95 ± 3.09	*33.86 ± 2.94	*‡37.95 ± 4.82	< 0.01
Neck circumference (cm)	34.52 ± 3.27	*38.22 ± 2.94	*‡41.64 ± 4.49	< 0.01
Waist circumference (cm)	83.36 ± 9.84	*97.83 ± 9.6	*‡109.13 ± 14.83	< 0.01
Waist/hip ratio	0.87 ± 0.05	*0.95 ± 0.05	*0.99 ± 0.07	< 0.01
*) compared to tertile 1, p < 0.05, ‡) compared tertile 2, p < 0.05				

Correlation between body components and others with the HOMA-IR

Pearson correlation analysis was performed to evaluate the linear relationships between HOMA-IR and various body composition variables. HOMA-IR exhibited strong positive correlations with body weight, fat mass, BMI, body fat percentage, and circumferences of the neck, abdomen, and hip (all $p < 0.05$).

Notably, HOMA-IR showed significant negative correlations with the ratios of leg muscle mass to fat mass, skeletal muscle to fat mass, and thigh/calf circumference to waist circumference (Fig. 2). These findings suggest that a higher proportion of lower-limb muscle relative to adiposity is closely associated with lower insulin resistance.

Subgroup analysis by sexual differences

Given the natural differences in body composition and muscle distribution between sexes, a subgroup analysis was conducted for male and female participants. The significant differences across HOMA-IR tertiles observed in the total population were largely maintained in both sexes (**Supplementary Tables 1 and 2**). Interestingly, correlation analyses revealed that body weight and waist-to-hip ratio were the most prominent factors correlated with HOMA-IR in men. In contrast, muscle mass indices, specifically the leg muscle-to-fat ratio, demonstrated stronger negative correlations with HOMA-IR in women compared to men.

Discussion

An improvement in HbA1c had often observed after some aerobic exercises in type 2 diabetic patients without any body weight change.[6,7] It reminds us that body composition change might be related closely to the body glucose level. IR is important factor for modifying glucose level in type 2 diabetic patients and the efforts for reducing IR should be continued.

We investigated the factors related to IR and body composition by BIA values. This study demonstrated that AC, NC, and muscle mass were related to IR in addition to body weight, BMI and waist related value. The control of body weight was proven to be helpful for delaying the type 2 diabetes mellitus progression[8–12] and its beneficial effects.[13–15] The weight loss and BMI reduction are associated with improvement in cardiovascular outcomes and complication risk in terms of better glucose control. However in the Action for Health in Diabetes (Look AHEAD) trial did not show the cardiovascular risk reduction by intensive lifestyle intervention for promoting weight loss in obese diabetic patients[16] although a post hoc analysis suggested its possibility of the beneficial effects.[17] Also, we often can observe the patients with body weight loss despite persisting hyperglycemia, therefore, there may be some differences between weight loss caused by an hypercatabolism and by intensive lifestyle interventions. So, the weight reduction is not just a predictive marker of well controlled glucose status. To date, most of the studies have targeted obesity and body weight. However, various metabolic diseases may also occur in patients with loss of muscle mass and strength such as sarcopenia. The sarcopenic patients with obesity had tendency to have poorly controlled glucose level in previous study.[18] Also, the IR was reported its relationship with the visceral fat to skeletal muscle ratio in middle aged women previously.[19]

So, our study which was evaluated the body composition factors by BIA and compared with glucose control status and/or IR has specific clinical meanings. We conducted this study under the assumption that exercise and lifestyle modifications for weight reduction are important, but other parameters should be managed together for better glucose control. As in previous studies,[20] this study also defined the importance of BMI and body weight for glucose control again. Additionally, this study concluded that AC, NC and waist related parameters were the important factors associated with IR as well. Studies have shown that NC contributes to an increase in cardiovascular mortality due to metabolic syndrome and sleep apnea.[21,22] In addition, a number of studies have shown that NC is related to IR.[23,24] The calculation of the mid-upper AC using anthropometric methods has also been studied, is associated with cardio-metabolic risk and IR.[25,26] These factors are mostly related to aerobic exercise in order to modify.

Another important aspect of this study was the relationship between muscle mass and IR. Several studies have shown that sarcopenic obesity is associated with an increased prevalence of metabolic syndrome and type 2 DM.[27–29] In the present study, we tried to analyze this point through each BIA factor and found that the high muscle mass to body fat ratio and leg (calf and thigh) circumference to waist ratio showed negative correlation with HOMA-IR. These association tendencies were more dominant for female patients. This meant that strength exercise or isometric exercise for increasing muscle mass also was a necessary condition to improve IR and the ratio of body muscle and fat is important also. The prominent negative correlation between leg muscle proportion and IR observed in our study is physiologically highly plausible. Skeletal muscle is the primary tissue responsible for insulin-stimulated glucose disposal, acting as the major "glucose sink" in the human body. Because the lower extremities—specifically the thigh and calf muscles—comprise the largest reservoir of skeletal muscle mass, preserving or increasing this specific regional muscle mass can disproportionately enhance glucose clearance and thereby lower HOMA-IR.

This physiological advantage becomes exceptionally critical when considering the practical challenges of sustaining physical activity during unforeseen environmental restrictions. As witnessed during the COVID-19 pandemic, the conventional reliance on outdoor aerobic exercises left many diabetic patients vulnerable to glycemic deterioration when quarantine measures were enforced. In contrast, lower-limb strength and isometric exercises, such as squats, chair rises, and stair climbing, require minimal space and no specialized equipment. Any part of the body muscle would be helpful, leg exercise will be more helpful in particular because it can be done easily in daily lives. Consequently, prioritizing lower-limb muscle strengthening provides a highly resilient and practical therapeutic strategy for type 2 DM management. It empowers patients to independently manage their metabolic control through body composition improvement, seamlessly bridging the gap when traditional outdoor activities are severely limited.

When BIA is used to assess the effects of weight control and exercise in the clinical field, a large amount of information is generated. Since a BIA can also provide information on various muscle and fat mass factors, this information can be used to obtain a deeper understanding of the impact of these factors on the severity of type 2 diabetes mellitus. However, variables such as weight and fat mass had been mainly

used and emphasized until now. In our BIA study, we found that BMI improvement through the weight reduction by aerobic exercise and muscle mass improvement, especially leg exercise, might be helpful for glucose control in patients with type 2 diabetes mellitus. However, the effect of this might be different between the man and the woman because of their different body composition in nature.

Our study has several notable limitations. First and foremost, the cross-sectional, observational design of this study precludes the establishment of a definitive causal relationship between lower-limb muscle proportions and insulin resistance. Because we did not apply serial interventions (e.g., a structured exercise program) to track intra-individual changes over time, we cannot definitively assert that increasing a patient's muscle mass will directly result in an improvement in HOMA-IR. The findings represent an association rather than a proven cause-and-effect mechanism. Therefore, future longitudinal and prospective interventional studies are required to verify whether directly modifying these BIA parameters yields tangible glycemic benefits. Second, the sample size in our study was relatively small, which may limit the generalizability of our findings. A larger-scale cohort is needed to raise the statistical confidence of this theory. Lastly, because we restricted our study to early type 2 DM patients (disease duration < 5 years), we cannot extrapolate the long-term effects of BIA-measured muscle mass in patients with prolonged disease durations, who may have other confounding factors such as severely depleted residual beta-cell function.

In conclusion, the increasing muscle mass including body weight reduction is important for improving IR especially in early type 2 diabetic patients. In during the COVID pandemics, the management of chronically ill patients demanding constant supervision, especially diabetic patients, was hard to control indeed. This phenomenon might be incurred by preventive strategy against COVID made the patients hospital visits hard. At the same time, overall physical activity decline might be related. During this unforeseen circumstances, in-hospital management and individual management were insufficient simultaneously. Judging from our study, the strength exercise for body muscle improvement can be beneficial to glucose control although the aerobic exercise for weight reduction did not execute due to the space limitation. And among the strength exercise, leg exercise such as chair climb and squatting at home could be beneficial if the outdoor activities is limited. It would be a good idea that every physician treating diabetes and diabetic patients keep this in mind. Further clinical investigations are required in future studies.

Materials and Methods

Participants and study protocol

As a retrospective study, patients with diagnosed type 2 DM less than 5 years were enrolled during December 2019 to December 2023. All participants only took the oral antidiabetic medication and all of them got basic blood test and bioelectrical impedance test within their first as the routine clinical practices.

This retrospective study was approved by the Institutional Review Board (IRB) of Inje University Haeundae Paik Hospital (HPIRB 2024-01-007). The requirement for obtaining informed consent was waived by the IRB of Inje University Haeundae Paik Hospital due to the retrospective nature of the study. All participant data were encrypted and anonymized to protect private information, strictly adhering to the Declaration of Helsinki.

Measurement of biochemical profiles

The blood test was consisted with blood glucose, C-peptide, total cholesterol, triglyceride, high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and glycated hemoglobin (HbA1c) at their first visit. Blood samples were drawn after more than 10 hours fasting.

Measurement of insulin resistance and beta-cell function

The homeostasis model assessment of IR (HOMA-IR) was used as a marker of IR using the HOMA2 model.[30] The HOMA2 model is available from www. OCDEM.ox.ac.uk or from J.C.L. or D.R.M. HOMA-IR was calculated with the Oxford University calculator using fasting glucose and C-peptide levels. We also calculated the insulin sensitivity (HOMA-IS, %S) and beta-cell function (HOMA-B, %B) through this model. The degree of HOMA-IR index was divided by 3 categories, 1st tertile ≤1.6, 2nd tertile; over 1.6 ~ 2.5, and 3rd tertile; ≥ 2.5. The upper (3rd) tertile was reguarded as highest insulin resistance among them.

Measurement of body composition

The BIA provided information about the body composition; an Inbody 370 composition analyzer (Inbody, Cerritos, California) was used. The data showed the levels of the weight, skeletal muscle mass, percent body fat at different sites and additional parameters such as circumferences of arm, neck, waist, hip, thigh and leg. Also, the rative fat mass (RFM) was calculated by according equation; 64-(20 x height/ waist circumference) for male and 76-(20 x height/ waist circumference).

Statistical analysis

The data are presented as frequencies with percentages for the categorical variables and means ± standard deviations (SD) for the continuous variables. The normality of the data distribution was assessed using the Shapiro-Wilk test. Pearson correlation coefficients were used to assess the correlation between two numeric variables. For the correlation coefficients, scores of between -1 and 1 were reported (0 indicated no agreement, 1 signified a perfect positive correlation, and -1 signified a perfect negative correlation). Differences in the study participants' characteristics were compared across the subgroups using the ANOVA. Box plots are presented for the visualization of the data. All the statistical analyses were performed using SPSS 25.0 (IBM, Armonk, NY, USA) and *P* values less than 0.05, were considered to be statistically significant.

Declarations

Competing interests:

The authors declare no competing interests.

Funding Declaration

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Author Contribution

JHK and SP conceptualized and designed the study. SP, CMH and JHK collected and organized the clinical data. BSP and KMP performed the statistical analysis. SP and JHK rafted the manuscript. All authors reviewed and approved the final version of the manuscript.

Acknowledgement

none

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to patient privacy and confidentiality requirements, but are available from the corresponding author on reasonable request

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Figures

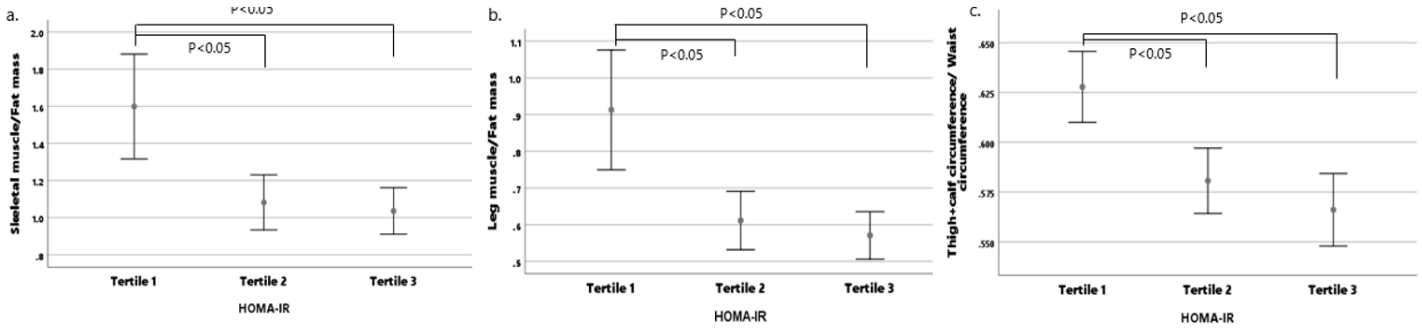


Figure 1

Distribution of leg muscle mass and circumference indices by HOMA-IR tertiles

Bar graphs represent the mean values of (a) skeletal muscle/fat mass ratio and (b) leg muscle/fat mass ratio, and (c) the ratio of thigh and calf circumference to waist circumference. All indices were highest in the lowest HOMA-IR tertile (group 1) and significantly decreased as insulin resistance increased. Statistical significance was determined by ANOVA ($p < 0.05$).

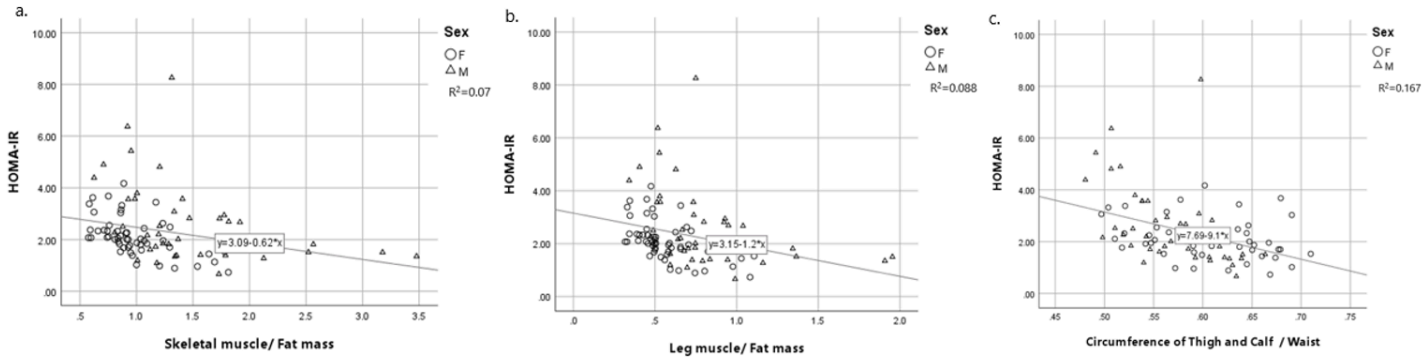


Figure 2

Correlation between leg muscle/ circumference proportions and HOMA-IR.

Scatter plots showing significant negative correlations between HOMA-IR and various leg indices: (a) skeletal muscle to fat mass ratio, (b) leg muscle to fat mass ratio, and (c) the ratio of thigh and calf circumference to waist circumference. Circles represent female participants and triangle represent male participants. The consistent downward trend across all panels indicates that a higher proportion of leg muscle is associated with lower insulin resistance.

Supplementary Files

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