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Correlation between skeletal muscle mass and islet function in patients with type 2 diabetes mellitus

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Abstract: Objective To investigate the correlation between skeletal muscle mass and islet function, skeletal muscle mass and insulin resistance (IR) in patients with type 2 diabetes mellitus (T2DM), and to elaborate the clinical significance of skeletal muscle mass in the maintenance of blood glucose homeostasis. diabetes mellitus (T2DM), and to elaborate on the clinical significance of skeletal muscle mass in the maintenance of blood glucose homeostasis. **Methods** A total of 274 adult T2DM patients hospitalized in the Department of Endocrinology (DOE) were treated for T2DM. total of 274 adult T2DM patients hospitalized in the Department of Endocrinology, the First Affiliated Hospital with Nanjing Medical University from August 2023 to February 2024 were retrospectively analyzed. The basic information of patients was collected, the grip strength of patients was measured, and the blood and urine samples were taken into account. The basic information of patients was collected, the grip strength of patients was measured , and the blood and urine were taken for biochemical detection. Bioelectrical impedance analysis (BIA) was used to measure the skeletal muscle content of the upper and lower limbs, viscosity, and other parameters. The upper and lower limbs, visceral fat area (VFA) and waist circumference fat weight, and the skeletal muscle index (SMI) and appendicular skeletal muscle index (ASMI) were calculated ,respectively. Pearson correlation method was used to analyze the correlation of grip strength, SMI and ASMI levels with blood glucose, insulin and C-peptide levels, islet β cell function indicators [islet β cell function (HOMA-β), corrected insulin reactivity (CIR), insulinogenic index (IGI)], and homeostatic model assessment for insulin resistance (HOMA-IR) and insulin sensitivity index (ISI). Multiple linear regression was further used to analyze the correlation between skeletal muscle mass and islet function in T2DM patients with different VFA and BMI. **Results** In T2DM patients, fasting blood glucose and insulin, while 120-minute postprandial blood glucose, and HOMA-IR were negatively correlated with grip strength levels (P<0.05). 120-minute postprandial insulin was positively correlated with grip strength levels (P<0.05). SMI and ASMI were negatively correlated with blood glucose at different time points of glucose tolerance in T2DM patients (P<0.01), and positively correlated with serum C-peptide levels and HOMA-β, CIR, and IGI, respectively (P<0.05). The level of SMI in lower limbs was negatively correlated with blood glucose at different time points of glucose tolerance (P<0.01), and positively correlated with insulin, C-peptide at different time points, and HOMA-β, IGI and CIR in T2DM patients (P<0.05). However, except for the negative correlation between SMI level and 2-hour blood glucose (P=0.019), there was no correlation between SMI level of upper limbs and other indicators mentioned above (P>0.05). After adjusting for gender and age, BMI stratified analysis showed that the correlations of SMI level with HOMA-β, IGI and CIR were significant in the normal BMI subgroup (P_{adj}<0.05), but not significant in the overweight and obese subgroups (P_{adj}>0.05), while the correlations of SMI level with HOMA-IR, ISI were not significant in the normal BMI subgroup (P_{adj}>0.05), but significant in the overweight and obese subgroups (P_{adj}<0.05). **Conclusion** Skeletal muscle mass is closely associated with blood glucose, islet function and IR in patients with T2DM. Increasing skeletal muscle mass of the whole body, especially that of the lower limbs and reducing the fat content accordingly play critical roles in the maintenance of glycemic homeostasis. Increasing skeletal muscle mass of the whole body, especially that of the lower limbs and reducing the fat content accordingly play critical roles in the maintenance of glycemic homeostasis and improving islet function in patients with T2DM.

Keywords: Type 2 diabetes mellitus; Skeletal muscle mass; Islet function; Insulin resistance; Glucose homeostasis
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Skeletal muscle, as one of the most significant tissues and organs in the human body, is one of the primary forms of protein in the body, accounting for 50% to 75% of the total protein, and plays a vital role in protein metabolism and nitrogen balance[1]. Skeletal muscle is also one of the significant organs of energy metabolism in the body, which is important for the maintenance of blood glucose homeostasis and the regulation of energy metabolism[2-3]. Skeletal muscle function and mass are closely related to insulin action and

pancreatic β-cell function. More and more studies have shown that decreased muscle mass is closely related to decreased glucose handling capacity and increased blood glucose in patients with type 2 diabetes mellitus (T2DM), but the correlation with pancreatic islet function is still unclear[4-5]. In this study, bioelectrical impedance analysis (BIA) was used to assess the relationship between skeletal muscle function and muscle mass with islet function and insulin resistance (IR) in patients with T2DM, and explored the role of upper and lower limb skeletal muscle content in patients with T2DM with different body mass indexes (BMIs), in order to clarify the significance of early assessment of skeletal muscle content and mass in the maintenance of glycemic homeostasis and adjustment of glucose-lowering regimen in diabetic patients, and to provide a theoretical basis for lifestyle intervention and glycemic control in diabetic patients.

1 Objects and Methods

1.1 Study objects

A total of 274 patients with T2DM who were hospitalized in the Department of Endocrinology of the First Affiliated Hospital of Nanjing Medical University (NMU) from August 2023 to February 2024 and who fulfilled the enrollment criteria (being able to walk freely and take care of their own lives basically) were selected for the retrospective study (Ethics No. 2021-SR-298). The diagnostic criteria for T2DM were adopted from the 1999 World Health Organization (WHO) diagnostic criteria. Exclusion criteria: (1) Combination of severe cardiac, hepatic and renal impairment or severe systemic diseases, bone and joint diseases, tuberculosis, tumors, severe depression, schizophrenia and other diseases; (2) Long-term bedridden, taking weight-loss medication, or having undergone bariatric surgery; (3) Taking medication such as glucocorticoids, growth hormone, thyroid hormone, and sex hormones; and (4) Cognitive dysfunction that could not be cooperated with the patients.

1.2 General data collection

General data such as gender, age, height, weight, duration of diabetes mellitus, recent medication use, history of smoking and alcohol consumption were collected, and BMI was calculated.

1.3 Laboratory indexes testing

Venous blood was collected from the study subjects on the following morning after 8-hour fasting and morning urine was retained for collection. Glycated hemoglobin (HbA1c), fasting blood glucose, fasting insulin, C-peptide, alanine aminotransferase (ALT), aspartate aminotransferase (AST), total cholesterol (TC), triacylglycerol (TG), low-density lipoprotein cholesterol (LDL-C), high density lipoprotein cholesterol (HDL-C), procalcitonin (PCT), 25-hydroxyvitamin D [25-(OH)D], serum albumin (ALB), thyroid function [free triiodothyronine (FT3), free thyroxine (FT4), thyroid-stimulating hormone (TSH)], urea, creatinine, 24-hour urinary proteins, and urinary albumin/creatinine ratio (UACR).

1.4 Insulin secretion and measurement of IR level

Glucose tolerance test was carried out after intensive insulin treatment for the study subjects to reach a stable state of blood glucose, 3 days before the assessment to maintain normal eating, at least 8 hours after the next morning without any calorie intake in the fasting state of the steamed buns (100 g) test. Fasting blood glucose, insulin and C peptide samples were retained from the fasting state. Starting from the first bite of the steamed buns, blood sampling were collected 30, 60 and 120 minutes to measure blood glucose, plasma insulin and C peptide levels. The levels of insulin secretion and IR were assessed by calculating the pancreatic β-cell function (HOMA-β) from the steady-state model and the homeostatic model assessment for insulin resistance (HOMA-IR), corrected insulin response (CIR), insulinogenic index (IGI), and insulin sensitivity index-Matsuda (Matsuda ISI).

1.5 Body composition analysis

Body composition analysis was performed using the BIA method (Instrument: Seca mBCA515, Germany) to determine the skeletal muscle content of the limbs and the whole body, resting energy expenditure, visceral fat area (VFA) and body fat percentage (BFP), bioelectrical impedance vector analysis (BIVA), and cellular phase angle of the subjects[6], and to calculate The skeletal muscle index (SMI), appendicular skeletal muscle mass (ASM = muscle content of both upper limbs and lower limbs), and the ASM index [ASMI = ASM (kg) / height^2 (m^2)]were calculated respectively.

1.6 Measurement of hand grip strength

The subjects' hand grip strength level was determined by a grip strength device (Jamar Digital Grip Strength Meter, USA), and the grip strength was measured 3 times using the dominant hand, respectively. Taking a rest interval of 1 minute after each test, and the maximum value of the 3 grip strength tests was taken.

1.7 Statistical methods

All data were analyzed using SPSS 25.0 and STATA 11.0 software. Normal distribution measurement data were expressed by $\bar{x}$ ±s , and independent samples t-test was used for comparison between two groups. Skewed distribution were expressed by M (P_{25}, P_{75}), and independent samples rank-sum test was used. Pearson

correlation analysis was used to analyze the correlation between pancreatic islet function and insulin sensitivity and SMI and ASMI, and multiple linear regression was used to analyze the effects of SMI on islet function and insulin sensitivity in patients with different visceral fat areas, different BMI levels, and in patients with T2DM, and the effects of SMI on islet function and insulin sensitivity in patients with T2DM. The effects of SMI on islet function and insulin sensitivity were analyzed in T2DM patients with different visceral fat areas and different BMI levels using multiple linear regression, corrected for variable factors such as age and gender.P < 0.05 was considered statistically significant.

2 Results

2.1 Basic information of study subjects

A total of 274 eligible T2DM patients were included in the study, including 160 males and 114 females, aged 22-87 years old. **Table 1** shows the basic information of study subjects with different genders, skeletal muscle strength and mass, glucose at different time points of glucose tolerance, insulin, C-peptide, islet β-cell function-related indexes (HOMA-β, IGI, CIR), HOMA-IR and Matsuda ISI results.

2.2 Correlation between hand grip strength, skeletal muscle mass and islet function in patients with T2DM

The results of Pearson correlation analysis showed that: (1) fasting glucose, insulin, 2-hour postprandial blood glucose, and HOMA-IR in patients with T2DM were significantly negatively correlated with the hand grip strength level (P<0.05). SMI and ASMI were significantly negatively correlated with glucose at different time points (P<0.01), and significantly correlated with serum C-peptide levels and islet β cell function (HOMA-β, IGI, and CIR) (P<0.05). (2) Lower limb SMI levels in patients with T2DM had a significantly negative correlation with blood glucose (P<0.01), and a significantly positive correlation with insulin, C-peptide, HOMA-β, IGI and CIR (P<0.05). The upper limb SMI level did not correlate with all of the above indicators except for a negative correlation with 2-hour blood glucose (P >0.05). **[Table 2]**

2.3 Effect of skeletal muscle mass on islet function in T2DM patients with different VFA

The effect of SMI levels on pancreatic β-cell function and IR in T2DM patients with different VFA was further analyzed using multiple linear regression, corrected for factor variables (age and gender). The results showed that in the overall study population, SMI level was significantly and positively correlated with HOMA-β, IGI, CIR and HOMA, respectively (P_{adj}<0.01), and significantly and negatively correlated with ISI (P_{adj}<0.01). when VFA<100 cm^2, there was no correlation between SMI level and HOMA-IR, and between SMI level and ISI (P_{adj}>0.05). However, when VFA ≥100 cm^2, there was a significant correlation between SMI level and HOMA-IR, and between SMI level and ISI (P_{adj}<0.01). **[Table 3]**

2.4 Effects of skeletal muscle mass on islet function in T2DM patients with different BMI levels

T2DM patients were stratified by BMI into normal group (BMI<24 kg/m^2), overweight group (24≤BMI<28 kg/m^2) and obese group (BMI≥28 kg/m^2). Multiple linear regression was used to analyze the effects of SMI levels in T2DM patients with different BMIs on islet function and IR/insulin sensitivity. The effects on islet function and IR were analyzed by multiple linear regression, corrected for factor variables (age and gender). The results showed that in the subgroup with normal BMI, SMI level showed a significantly positive correlation with islet β-cell function indexes (HOMA-β, IGI, CIR) (P_{adj}<0.05), and no correlation with IR/insulin sensitivity indicators (HOMA-IR and ISI) (P_{adj}>0.05). In overweight and obese subgroups, SMI levels did not show a correlation with IGI and CIR (P_{adj}>0.05), and a significant correlation with HOMA-IR and ISI (P_{adj} <0.05). **[Table 4]**

2.5 Effects of upper and lower limb SMI on islet function in T2DM patients with different BMI subgroups

The effects of upper and lower limb SMI levels on pancreatic β-cell function and IR/insulin sensitivity, respectively, were analyzed by multiple linear regression and corrected for the factor variables (age and gender) in T2DM patients with different BMI. HOMA-IR were negatively correlated (P_{adj}<0.05) and positively correlated with ISI (P_{adj}<0.05). In the obese subgroup, both upper limb SMI and lower limb SMI levels were positively correlated with HOMA-β (P_{adj}<0.05), whereas upper limb SMI was positively correlated with ISI (P_{adj}=0.043) and lower limb SMI was negatively correlated with ISI (P_{adj}<0.05). **[Table 5]**

Tab. 1 Basic information of all patients

Basic information	Female (*n*=114)	Male (*n*=160)
Age[a]	60.360 ± 15.152	58.540 ± 12.926
BMI (kg/m²)[a]	25.478 ± 4.605	25.008 ± 3.147
Hand grip strength (kg)[a]	20.953 ± 6.260	35.337 ± 7.773
SMI (kg/m²)[a]	6.447 ± 1.362	8.447 ± 1.006
Blood glucose (mmol/L)[a]		
0 min	7.565 ± 1.958	6.833 ± 1.814
30 min	10.978 ± 2.730	10.374 ± 2.500
120 min	16.979 ± 4.139	16.157 ± 3.761
Insulin (pmol/L)[b]		
0 min	47.450 (23.300, 92.325)	38.200 (22.500, 68.000)
30 min	102.1500 (57.183, 167.225)	97.0400 (49.450, 168.500)
120 min	195.350 (105.975, 359.300)	162.7000 (96.500, 285.100)
C-peptide (pmol/L)[b]		
0 min	559.400 (377.550, 848.275)	582.100 (388.600, 850.300)
30 min	807.550 (606.475, 1226.500)	812.300 (582.700, 1208.000)
120 min	1567.000 (1075.000, 2318.750)	1712.000 (1077.000, 2424.000)
HbA1c (%)[a]	8.624 ± 2.429	8.456 ± 1.710
IR or sensitivity[b]		
HOMA-IR	2.681 (1.457, 4.616)	1.648 (1.035, 2.417)
Matsuda ISI	4.733 (2.511, 8.811)	7.340 (5.086, 13.030)
Pancreatic function[b]		
HOMA-β	54.701 (21.817, 113.789)	39.271 (15.715, 74.135)
IGI	2.703 (0.705, 5.572)	2.122 (1.123, 3.488)
CIR	26.489 (11.615, 63.286)	22.572 (9.773, 46.423)

Note: [a] represents data in the form of $\bar{x} \pm s$; [b] represents data in the form of M (P_{25} , P_{75}).

Tab. 2 Correlation between hand grip strength, skeletal muscle mass and islet function in patients with T2DM

Index	Grip strength		ASMI		SMI		Upper limb SMI SMI		Lower limb SMI	
	r value	*P* value	*r* value	*P* value	*r* value	*P* value	*r* value	*P* value	*r* value	*P* value
Blood glucose										
0 min	-0.085	0.026	-0.219	0.001	-0.274	<0.001	-0.117	0.086	-0.239	<0.001
30 min	-0.076	0.367	-0.220	0.001	-0.246	<0.001	-0.127	0.065	-0.235	0.001
120 min	-0.206	0.013	-0.311	<0.001	-0.309	<0.001	-0.160	0.019	-0.342	<0.001
Insulin										
0 min	-0.187	0.025	0.130	0.058	0.137	0.045	0.026	0.709	0.162	0.017
30 min	-0.078	0.361	0.089	0.200	0.123	0.074	-0.052	0.454	0.144	0.037
120 min	0.180	0.033	0.089	0.195	0.115	0.092	-0.031	0.649	0.134	0.049
C-peptide										
0 min	-0.127	0.128	0.200	0.003	0.205	0.002	0.091	0.178	0.225	0.001
30 min	-0.052	0.541	0.195	0.004	0.210	0.003	0.057	0.409	0.235	0.001
120 min	-0.053	0.529	0.162	0.017	0.183	0.007	0.040	0.562	0.199	0.003
HbA1c	-0.051	0.538	0.002	0.979	0.017	0.800	-0.006	0.932	0.005	0.940
HOMA-IR	-0.223	0.008	0.075	0.275	0.070	0.307	0.001	0.990	0.100	0.143
Matsuda ISI	-0.222	0.008	-0.066	0.399	-0.075	0.275	0.023	0.740	-0.099	0.148
HOMA-β	-0.034	0.685	0.197	0.004	0.220	0.001	0.072	0.295	0.231	0.001
IGI	-0.016	0.856	0.159	0.024	0.166	0.019	0.095	0.180	0.175	0.013
CIR	-0.016	0.847	0.184	0.008	0.224	0.001	0.024	0.733	0.236	0.001

Tab.3 Correlation between skeletal muscle mass and islet function in T2DM patients with different VFA

SMI	Overall population		VFA <100 cm²		VFA ≥100 cm²	
	β	P_{adj}	*β*	P_{adj}	*β*	P_{adj}
Pancreatic function						
HOMA-β	0.483	<0.001	0.266	0.073	0.574	0.003
IGI	0.483	<0.001	0.308	0.042	0.302	0.149
CIR	0.562	<0.001	0.407	0.007	0.464	0.024
IR/insulin sensitivity						
HOMA-IR	0.357	0.001	0.047	0.754	0.525	0.007
Matsuda ISI	-0.394	<0.001	-0.068	0.646	-0.525	0.006

Tab.4 Correlation between skeletal muscle mass and islet function in T2DM patients with different BMIs

SMI	Normal		Overweight		Obese	
	β	P_{adj}	β	P_{adj}	β	P_{adj}
Pancreatic function						
HOMA-β	0.387	0.046	0.021	0.917	0.534	0.039
IGI	0.424	0.032	0.284	0.156	0.253	0.370
CIR	0.442	0.023	0.335	0.099	0.431	0.105
IR/insulin sensitivity						
HOMA-IR	0.316	0.106	-0.451	0.017	0.603	0.017
Matsuda ISI	-0.368	0.058	0.440	0.020	-0.647	0.009

Tab.5 Effects of upper and lower limb skeletal muscle mass on islet function in T2DM patients with different BMIs

SMI	Normal				Overweight				Obese			
	Upper limb SMI		Lower limb SMI		Upper limb SMI		Lower limb SMI		Upper limb SMI		Lower limb SMI	
	β	P_{adj}	β	P_{adj}	β	P_{adj}	β	P_{adj}	β	P_{adj}	β	P_{adj}
Pancreatic function												
HOMA-β	-0.049	0.688	0.233	0.113	0.085	0.665	-0.119	0.439	0.551	0.032	0.593	0.008
IGI	0.186	0.290	0.238	0.110	0.212	0.281	0.088	0.572	0.061	0.829	0.253	0.313
CIR	-0.131	0.286	0.273	0.063	0.249	0.213	0.081	0.600	0.413	0.120	0.446	0.056
IR/insulin sensitivity												
HOMA-IR	0.044	0.722	0.227	0.124	-0.371	0.047	-0.366	0.012	0.489	0.054	0.544	0.014
Matsuda ISI	0.001	0.996	-0.198	0.180	0.370	0.048	0.351	0.016	0.506	0.043	-0.583	0.007

3 Discussion

This study analyzed the correlation of skeletal muscle content with pancreatic β-cell function and IR in patients with T2DM, and further explored the significance of upper and lower limb skeletal muscle content in patients with T2DM with different levels of visceral adiposity and BMI, and the results showed that the skeletal muscle function and content of the patients were closely correlated with the levels of blood glucose, pancreatic β-cell function, and IR, and the correlation of the level of the lower extremities with blood glucose, insulin, C-peptide, and IR was more significant than the level of the upper limb SMI. Compared with upper limb SMI, lower limb SMI levels were more significantly correlated with blood glucose, insulin, C-peptide and islet β-cell function at different time points in T2DM patients. Therefore, increasing lower limb SMI levels is important for improving blood glucose, pancreatic β-cell function and IR in T2DM patients. In addition, in the overweight T2DM subgroup, increased upper and lower limb SMI levels had a significant effect on improving IR and insulin sensitivity, whereas the significance in T2DM patients with excess VFA or obesity is unclear.

Muscle content, especially skeletal muscle content, is important for the treatment and prognosis of patients with T2DM. Skeletal muscle content, mass and strength should be assessed early in diabetic patients, especially those with high-risk factors[7-8]. Currently, the most commonly used methods for skeletal muscle measurement include anthropometric methods, BIA, ultrasound, dual-energy X-ray absorptiometry (DXA), computed tomography (CT), and magnetic resonance imaging (MRI) [9-10]. The above measurement methods are used in different scenarios and have their advantages and disadvantages, but since Lukaski first proposed the use of BIA to evaluate body composition in 1985, the application of BIA has received more and more attention and popularization due to its safe, convenient, non-invasive and economic features[11-13]. BIA is mainly based on the degree of flow of low-voltage electric current in the body to non-invasively analyze and measure body composition such as fat, muscle water, etc. It is suitable for clinical evaluation and determination. BIA is suitable for clinical evaluation and rapid body composition testing[14]. Several clinical studies have demonstrated the consistency and reliability of BIA with DXA and MRI, but there is still some controversy in some studies that require more accurate assessment[15].

Skeletal muscle is one of the most important organs and tissues for glucose utilization and energy metabolism in the body, and its content is important for the maintenance of glucose homeostasis in T2DM patients[16]. Insulin-mediated glucose uptake occurs mainly in skeletal muscle, and an increase in its content can directly increase basal metabolic rate and energy expenditure[17]. Skeletal muscle content plays an important role in insulin sensitivity, and IR is closely related to mitochondrial content and function. Skeletal muscle cell mitochondrial abnormalities may accelerate the progression of IR by increasing the production of reactive oxygen species[18-19]. In addition, it has been reported that skeletal muscle cells can play an important role in regulating pancreatic β-cell function through the secretion of cytokines, but the specific mechanism is not yet fully understood[20]. Patients with T2DM are prone to obesity with sarcopenia, and the reduction of skeletal muscle mass is closely related to glucose metabolism disorders. Sarcopenic obesity was first proposed by Baumgartner *et al.* in 2000, i.e., the coexistence of sarcopenia and obesity, but there is still a lack of unified diagnostic criteria[21]. Compared with sarcopenia alone, sarcopenic obesity is significantly associated with increased IR, cardiovascular disease and mortality[22-23]. The results of the current studies suggest that increasing skeletal muscle content is important for improving pancreatic β-cell function and IR in normal and overweight states, but this correlation is attenuated or disappears in visceral fat excess or obesity states. In addition, compared with upper limb SMI levels, lower limb SMI levels correlated more significantly with blood glucose and pancreatic β-cell function in T2DM patients. Therefore, increasing the skeletal muscle content of diabetic patients, especially in the lower limbs, and decreasing the fat content accordingly are valuable for the maintenance of glycemic homeostasis and the improvement of pancreatic β-cell function.

Muscle content, mass and function are closely related to the nutritional status and overall metabolic level of T2DM patients. Lifestyle interventions including dietary management and exercise training are important measures to prevent and improve islet function in diabetic patients[24-25]. Currently, hypoglycemic drugs may have certain effects on muscle mass in T2DM patients, for

example, sulfonylureas, glinides, thiazolidinediones, and dipeptidyl peptidase IV inhibitors (DPP-4i) are potentially associated with reduced muscle mass or decreased muscle mass[26]. Therefore, when choosing hypoglycemic drugs and regimens for different patients, individual variability of the patients should be taken into account to choose the appropriate hypoglycemic regimen for them [27-28]. In addition, early measurement and assessment of muscle content, especially skeletal muscle mass, in T2DM patients by BIA and other methods, and guidance for patients to adjust the treatment or adopt appropriate interventions and training measures when necessary, are of great significance to the glycemic control of diabetic patients and the prevention and treatment of long-term complications.

Conflict of interest **None**

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·论　著·

2 型糖尿病患者骨骼肌质量与胰岛功能相关性研究

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摘要：目的　探讨 2 型糖尿病(T2DM)患者骨骼肌质量与胰岛功能及胰岛素抵抗的相关性,阐述其在血糖稳态中的临床意义。**方法**　选择 2023 年 8 月至 2024 年 2 月于南京医科大学第一附属医院内分泌科住院治疗的成年 T2DM 患者共 274 例进行回顾性分析,收集患者基本信息,测定患者握力水平并留取血液及尿液进行生化检测,通过生物电阻抗分析法(BIA)测定患者上下肢骨骼肌含量、内脏脂肪面积(VFA)及腰围等,分别计算骨骼肌质量指数(SMI)及四肢骨骼肌质量指数(ASMI)。采用 Pearson 相关法分析患者握力值、SMI 及 ASMI 水平与血糖、胰岛素及 C 肽水平、胰岛 β 细胞功能指标[胰岛 β 细胞功能(HOMA-β)、校正胰岛素反应性(CIR)、胰岛素生成指数(IGI)]、稳态模型胰岛素抵抗指数(HOMA-IR)和胰岛素敏感指数(ISI)的相关性,进一步用多重线性回归分析不同 VFA、不同 BMI 水平 T2DM 患者骨骼肌质量与胰岛功能的相关性。**结果**　T2DM 患者空腹血糖及胰岛素、餐后 120 min 血糖及 HOMA-IR 与握力水平呈显著负相关(P<0.05),而餐后 120 min 胰岛素与握力水平呈正相关(P<0.05)。SMI 及 ASMI 与 T2DM 患者糖耐量不同时点血糖分别呈负相关(P<0.01),与血清 C 肽水平及 HOMA-β、CIR、IGI 分别呈正相关(P<0.05)。下肢 SMI 水平与 T2DM 患者糖耐量不同时点血糖均呈负相关(P<0.01),与不同时点胰岛素、不同时点 C 肽及 HOMA-β、IGI 和 CIR 均呈正相关(P<0.05);但上肢 SMI 水平除与 120 min 血糖存在负相关(P=0.019)外,与上述其他指标无相关性(P>0.05)。校正性别和年龄后 BMI 分层分析显示,SMI 水平与 IOMA-β、IGI、CIR 的相关性在 BMI 正常亚组显著(P_{adj}<0.05),在超重、肥胖亚组不显著(P_{adj}>0.05);而 SMI 水平与 HOMA-IR、ISI 的相关性却在 BMI 正常亚组不显著(P_{adj}>0.05),在超重、肥胖亚组显著(P_{adj}<0.05)。**结论**　骨骼肌质量与 T2DM 患者血糖、胰岛功能及胰岛素抵抗密切相关,提高全身骨骼肌尤其是下肢骨骼肌含量及相应减少脂肪含量对于 T2DM 患者血糖稳态维持及胰岛功能改善具有重要意义。

关键词： 2 型糖尿病；骨骼肌质量；胰岛功能；胰岛素抵抗；血糖稳态
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Correlation between skeletal muscle mass and islet function in patients with type 2 diabetes mellitus

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Abstract: Objective　To investigate the correlation between skeletal muscle mass and islet function, skeletal muscle mass and insulin resistance in patients with type 2 diabetes mellitus (T2DM), and to elaborate on the clinical significance of skeletal muscle mass in the maintenance of blood glucose homeostasis. **Methods**　A total of 274 adult T2DM patients hospitalized in the Department of Endocrinology, the First Affiliated Hospital with Nanjing Medical University from August 2023 to February 2024 were retrospectively analyzed. The basic information of patients was collected, the grip strength of patients was measured, and the blood and urine samples were taken for biochemical detection. Bioelectrical impedance analysis (BIA) was used to measure the skeletal muscle content of the upper and lower limbs, visceral fat area (VFA) and waist circumference. The skeletal muscle mass index (SMI) and appendicular skeletal muscle mass index (ASMI) were calculated, respectively. Pearson correlation method was used to analyze the

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QR code for English version

correlation of grip strength, SMI and ASMI levels with blood glucose, insulin and C-peptide levels, islet β cell function indicators [islet β cell function (HOMA-β), corrected insulin reactivity (CIR), insulinogenic index (IGI)], and homeostasis model assessment of insulin resistance (HOMA-IR) and insulin sensitivity index(ISI). Multirariable linear regression was further used to analyze the correlation between skeletal muscle mass and islet function in T2DM patients with different VFA and BMI. **Results** In T2DM patients, fasting blood glucose and insulin, 120-minute postprandial blood glucose, and HOMA-IR were negatively correlated with grip strength levels ($P<0.05$), while 120-minte postprandial insulin was positively correlated with grip strength levels ($P<0.05$). SMI and ASMI were negatively correlated with blood glucose levels at different time points of glucose tolerance in T2DM patients ($P<0.01$), and positively correlated with serum C-peptide levels, HOMA-β, CIR, and IGI, respectively ($P<0.05$). The level of SMI in lower limbs was negatively correlated with blood glucose levels at different time points of glucose tolerance ($P<0.01$), and positively correlated with insulin, C-peptide at different time points, as well as HOMA-β, IGI and CIR in T2DM patients ($P<0.05$); However, except for the negative correlation between SMI level of upper limbs and 120 min blood glucose ($P=0.019$), there was no correlation between SMI level of upper limbs and other indicators mentioned above ($P>0.05$). After adjusting for gender and age, BMI stratified analysis showed that the correlations of SMI level with HOMA-β, IGI and CIR were significant in the normal BMI subgroup ($P_{adj}<0.05$), but not significant in the overweight and obese subgroups ($P_{adj}>0.05$), while the correlations of SMI level with HOMA-IR , ISI were not significant in the normal BMI subgroup ($P_{adj}>0.05$), but significant in the overweight and obese subgroups ($P_{adj}<0.05$). **Conclusion** Skeletal muscle mass is closely associated with blood glucose, islet function and insulin resistance in patients with T2DM. Increasing skeletal muscle mass of the whole body, especially that of the lower limbs and reducing the fat content accordingly play critical roles in the maintenance of glycemic homeostasis and improving islet function in patients with T2DM.

Keywords: Type 2 diabetes mellitus; Skeletal muscle mass; Islet function; Insulin resistance; Glucose homeostasis

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骨骼肌作为人体最大的组织和器官之一,是人体内蛋白质的主要存在形式之一,占总蛋白质的50%~75%,在蛋白质代谢及氮平衡中发挥重要作用[1]。同时,骨骼肌也是体内主要的能量代谢器官之一,对机体血糖稳态维持及能量代谢调控具有重要意义[2-3]。骨骼肌功能及质量与胰岛素作用及胰岛 β 细胞功能密切相关,越来越多的研究也表明肌量下降与 2 型糖尿病(type 2 diabetes mellitus, T2DM)患者葡萄糖处理能力降低及血糖升高存在密切关联,但目前其与胰岛功能相关性尚不明确[4-5]。本研究通过使用生物电阻抗分析(bioelectrical impedance analysis, BIA)方法评估骨骼肌功能及肌肉质量与 T2DM 患者胰岛功能及胰岛素抵抗的关系,并探讨上、下肢骨骼肌含量在不同身体质量指数(body mass index, BMI)T2DM 患者中的作用,明确骨骼肌含量及质量早期评估在糖尿病患者血糖稳态维持及降糖方案调整中的意义,为糖尿病患者生活方式干预及血糖控制提供一定理论依据。

1　对象与方法

1.1　研究对象　选择 2023 年 8 月至 2024 年 2 月于南京医科大学第一附属医院内分泌科住院的 274 例 T2DM 患者作为对象进行回顾性研究(伦审号 2021-SR-298)。T2DM 诊断标准采用 1999 年世界卫生组织(WHO)诊断标准。入组标准:符合 1999 年 WHO 的 T2DM 诊断标准;能自由走动且生活基本自理。排除标准:(1) 合并严重心肝肾功能损害或严重全身性疾病、骨关节疾病、结核、肿瘤、严重抑郁、精神分裂等疾病;(2) 长期卧床、服用减肥药物或曾行减重手术;(3) 服用糖皮质激素、生长激素、甲状腺激素及性激素等药物;(4) 认知功能低下无法配合者。

1.2　一般资料收集　收集患者性别、年龄、身高、体重、糖尿病病程、近期用药情况、吸烟及饮酒史等基本信息,计算 BMI。

1.3　实验室指标检测　研究对象禁食 8 h 后于次晨空腹采集静脉血并留取收集晨尿。测定糖化血红蛋白(HbA1c)、空腹血糖、空腹胰岛素及 C 肽、丙氨酸氨基转移酶(ALT)、天门冬氨酸氨基转移酶(AST)、总胆固醇(TC)、三酰甘油(TG)、低密度脂蛋白胆固醇(LDL-C)、高密度脂蛋白胆固醇(HDL-C)、降钙素、25 羟维生素 D[25-(OH)D]、血清白蛋白(ALB)、甲状腺功能[游离三碘甲状腺原氨酸(FT3)、游离甲状

腺素(FT4)、促甲状腺激素(TSH)]、尿素、肌酐、24 h 尿蛋白、尿微量白蛋白/尿肌酐比值(UACR)等。

1.4　胰岛素分泌和胰岛素抵抗水平测定　对研究对象行胰岛素强化治疗待血糖达稳定状态后进行葡萄糖耐量试验,评估前 3 d 保持正常进食,在无任何热量摄入至少 8 h 后次晨空腹状态行馒头餐(100 g)试验,留取空腹状态血糖、胰岛素及 C 肽测定样本后,从吃馒头第一口开始计时,30、60 及 120 min 抽血测定血糖、血浆胰岛素及 C 肽水平。并通过计算稳态模型评估的胰岛 β 细胞功能(HOMA-β)和稳态模型评估的胰岛素抵抗性(HOMA-IR)、校正胰岛素反应性(CIR)、胰岛素生成指数(IGI)和 Matsuda 胰岛素敏感指数(Matsuda ISI)来评估胰岛素分泌和胰岛素抵抗水平。

1.5　身体成分测定分析　利用 BIA 法(仪器:Seca mBCA515,德国)进行身体成分分析,测定受试者四肢及全身骨骼肌含量、静息能量消耗、内脏脂肪面积(visceral fat area, VFA)和腰围、生物电阻抗矢量分析及细胞相位角等[6],并且分别计算骨骼肌质量指数(skeletal muscle mass index, SMI)、四肢骨骼肌质量(appendicular skeletal muscle mass, ASM)= 双上肢及双下肢肌肉含量,四肢骨骼肌质量指数(ASM index, ASMI)= ASM (kg) /身高^2(m^2)。

1.6　握力测定　通过使用握力器(Jamar 数字握力计,美国)测定受试者握力水平,分别利用优势手测定握力 3 次,每次测试后需休息间隔 1 min,取 3 次握力测试最大值。

1.7　统计学方法　所有数据采用 SPSS 25.0 及 Stata 11.0 软件进行统计分析。正态分布计量资料用 $\bar{x}\pm s$ 表示,两组间比较采用独立样本 t 检验;偏态分布资料以 $M(P_{25},P_{75})$ 表示,采用独立样本秩和检验;采用 Pearson 相关法分析胰岛功能及胰岛素敏感性与 SMI 及 ASMI 之间的相关性;用多重线性回归分析 SMI 对胰岛功能及胰岛素敏感性的影响,并对变量因素如年龄、性别等进行校正。P<0.05 为差异有统计学意义。

2　结　果

2.1　研究对象基本特征　共纳入符合条件的 T2DM 患者 274 例,其中男性 160 例,女性 114 例,年龄 22~87 岁,表 1 为不同性别研究对象基本特征、骨骼肌力量及质量、糖耐量不同时间点血糖、胰岛素及 C 肽结果、胰岛 β 细胞功能相关指标(HOMA-β、IGI、CIR)及 HOMA-IR 和 Matsuda ISI 结果。

2.2　T2DM 患者握力及骨骼肌质量与胰岛功能的相关性　Pearson 相关分析结果表明:(1) T2DM 患者空腹血糖和胰岛素、餐后 120 min 血糖及胰岛素抵抗相关指标 HOMA-IR 与握力水平呈显著负相关(P<0.05),餐后 120 min 胰岛素水平与握力呈正相关(P<0.05);骨骼肌质量相关指标 SMI 及 ASMI 与糖耐量不同时间点血糖均呈显著负相关(P<0.01),且与血清 C 肽水平及胰岛 β 细胞功能指标(HOMA-β、IGI 及 CIR)均呈显著正相关(P<0.05)。(2) T2DM 患者下肢 SMI 水平与血糖呈显著负相关性(P<0.01),而与胰岛素、C 肽及 HOMA-β、IGI、CIR 均呈显著正相关(P<0.05);而上肢 SMI 水平除与 120 min 血糖存在负相关(P=0.019)外,与上述其他各项指标无相关性(P>0.05)。见表 2。

表 1　所有患者基本信息

Tab. 1　Basic information of all patients

基本特征	女(n=114)	男(n=160)
年龄[a]	60.360±15.152	58.540±12.926
BMI(kg/m^2)[a]	25.478±4.605	25.008±3.147
握力(kg)[a]	20.953±6.260	35.337±7.773
SMI(kg/m^2)[a]	6.447±1.362	8.447±1.006
血糖(mmol/L)[a]		
0 min	7.565±1.958	6.833±1.814
30 min	10.978±2.730	10.374±2.500
120 min	16.979±4.139	16.157±3.761
胰岛素(pmol/L)[b]		
0 min	47.450(23.300,92.325)	38.200(22.500,68.000)
30 min	102.150(57.183,167.225)	97.040(49.450,168.500)
120 min	195.350(105.975,359.300)	162.700(96.500,285.100)
C 肽(pmol/L)[b]		
0 min	559.400(377.550,848.275)	582.100(388.600,850.300)
30 min	807.550(606.475,1 226.500)	812.300(582.700,1 208.000)
120 min	1 567.000(1 075.000,2 318.750)	1 712.000(1 077.000,2 424.000)
HbA1c (%)[a]	8.624±2.429	8.456±1.710
IR 或 IS[bc]		
HOMA-IR	2.681(1.457,4.616)	1.648(1.035,2.417)
Matsuda ISI	4.733(2.511,8.811)	7.340(5.086,13.030)
胰岛功能[b]		
HOMA-β	54.701(21.817,113.789)	39.271(15.715,74.135)
IGI	2.703(0.705,5.572)	2.122(1.123,3.488)
CIR	26.489(11.615,63.286)	22.572(9.773,46.423)

注:[a] 表示数据形式为 $\bar{x}\pm s$;[b] 表示数据形式为 $M(P_{25},P_{75})$;[c]IR 或 IS 表示胰岛素抵抗或敏感。

2.3　不同 VFA 的 T2DM 患者骨骼肌质量对胰岛功能的影响　进一步利用多重线性回归分析不同 VFA 的 T2DM 患者 SMI 水平对胰岛 β 细胞功能及胰岛素抵抗或敏感的影响,并对变量因素(年龄及性别)进行校正。结果表明,在整体研究对象中,SMI 水平与 HOMA-β、IGI 和 CIR 及 HOMA-IR 分别呈显著正相关(P_{adj}<0.01),与 ISI 呈显著负相关(P_{adj}<0.01)。在

VFA<100 cm^2 时,SMI 水平与 IGI、CIR 呈显著正相关(P_{adj}<0.01),与 HOMA-β 及 HOMA-IR、ISI 均无相关性(P_{adj}>0.05);但在内脏脂肪面积≥100 cm^2 时,SMI 水平与 HOMA-β、CIR 及 HOMA-IR 均呈显著正相关(P_{adj}<0.01),与 ISI 呈显著负相关(P_{adj}<0.01)。详见表 3。

2.4　不同 BMI 水平 T2DM 患者骨骼肌质量对胰岛功能的影响　将 T2DM 患者进行 BMI 分层,分为正常组(BMI<24 kg/m^2)、超重组(24 ≤ BMI<28 kg/m^2)及肥胖组(BMI ≥ 28 kg/m^2),采用多重线性回归分析不同 BMI 的 T2DM 患者 SMI 水平对胰岛功能及胰岛素抵抗或敏感的影响,对变量因素(年龄及性别)进行校正,结果表明在 BMI 正常亚组中,SMI 水平与胰岛 β 细胞功能指标(HOMA-β、IGI、CIR)呈显著正相关(P_{adj}<0.05),与胰岛抵抗或敏感指标(HOMA-IR、ISI)无相关性(P_{adj}>0.05);在超重和肥胖亚组中,SMI 水平与 IGI、CIR 未显示相关性(P_{adj}>0.05),与 HOMA-IR、ISI 分别呈正相关和负相关(P_{adj}<0.05)。见表 4。

2.5　不同 BMI 的 T2DM 患者上、下肢 SMI 对胰岛功能的影响　采用多重线性回归分析不同 BMI 的 T2DM 患者上、下肢 SMI 水平分别对胰岛 β 细胞功能及胰岛素抵抗或敏感的影响,并对变量因素(年龄及性别)进行校正,结果表明,在超重亚组中,上肢 SMI 及下肢 SMI 水平均与 HOMA-IR 呈负相关(P_{adj}<0.05),与 ISI 呈正相关(P_{adj}<0.05)。在肥胖亚组中,上肢 SMI 及下肢 SMI 水平均与 HOMA-β 呈正相关(P_{adj}<0.05),而上肢 SMI 与 ISI 呈正相关(P_{adj}=0.043),下肢 SMI 与 HOMA-IR、ISI 分别呈正相关和负相关(P_{adj}<0.05)。见表 5。

表 2　T2DM 患者握力、骨骼肌质量与胰岛功能的相关性

Tab. 2　Correlation between grip strength, skeletal muscle mass and islet function in patients with T2DM

指标	握力		ASMI		SMI		上肢 SMI		下肢 SMI	
	r 值	*P* 值	*r* 值	*P* 值	*r* 值	*P* 值	*r* 值	*P* 值	*r* 值	*P* 值
血糖										
0 min	−0.085	0.026	−0.219	0.001	−0.274	<0.001	−0.117	0.086	−0.239	<0.001
30 min	−0.076	0.367	−0.220	0.001	−0.246	<0.001	−0.127	0.065	−0.235	0.001
120 min	−0.206	0.013	−0.311	<0.001	−0.309	<0.001	−0.160	0.019	−0.342	<0.001
胰岛素										
0 min	−0.187	0.025	0.130	0.058	0.137	0.045	0.026	0.709	0.162	0.017
30 min	−0.078	0.361	0.089	0.200	0.123	0.074	−0.052	0.454	0.144	0.037
120 min	0.180	0.033	0.089	0.195	0.115	0.092	−0.031	0.649	0.134	0.049
C 肽										
0 min	−0.127	0.128	0.200	0.003	0.205	0.002	0.091	0.178	0.225	0.001
30 min	−0.052	0.541	0.195	0.004	0.210	0.003	0.057	0.409	0.235	0.001
120 min	−0.053	0.529	0.162	0.017	0.183	0.007	0.040	0.562	0.199	0.003
HbA1c	−0.051	0.538	0.002	0.979	0.017	0.800	−0.006	0.932	0.005	0.940
HOMA-IR	−0.223	0.008	0.075	0.275	0.070	0.307	0.001	0.990	0.100	0.143
Matsuda ISI	−0.222	0.008	−0.066	0.399	−0.075	0.275	0.023	0.740	−0.099	0.148
HOMA-β	−0.034	0.685	0.197	0.004	0.220	0.001	0.072	0.295	0.231	0.001
IGI	−0.016	0.856	0.159	0.024	0.166	0.019	0.095	0.180	0.175	0.013
CIR	−0.016	0.847	0.184	0.008	0.224	0.001	0.024	0.733	0.236	0.001

表 3　不同 VFA 的 T2DM 患者骨骼肌质量与胰岛功能相关性

Tab. 3　Correlation between skeletal muscle mass and islet function in T2DM patients with different VFAs

SMI	所有人群		VFA <100 cm^2		VFA ≥100 cm^2	
	β	P_{adj}	*β*	P_{adj}	*β*	P_{adj}
胰岛功能						
HOMA-β	0.483	<0.001	0.266	0.073	0.574	0.003
IGI	0.483	<0.001	0.308	0.042	0.302	0.149
CIR	0.562	<0.001	0.407	0.007	0.464	0.024
IR 或 IS						
HOMA-IR	0.357	0.001	0.047	0.754	0.525	0.007
Matsuda ISI	−0.394	<0.001	−0.068	0.646	−0.525	0.006

表 4　不同 BMI T2DM 患者骨骼肌质量与胰岛功能相关性

Tab. 4　Correlation between skeletal muscle mass and islet function in T2DM patients with different BMIs

SMI	正常		超重		肥胖	
	β	P_{adj}	*β*	P_{adj}	*β*	P_{adj}
胰岛功能						
HOMA-β	0.387	0.046	0.021	0.917	0.534	0.039
IGI	0.424	0.032	0.284	0.156	0.253	0.370
CIR	0.442	0.023	0.335	0.099	0.431	0.105
IR 或 IS						
HOMA-IR	0.316	0.106	−0.451	0.017	0.603	0.017
Matsuda ISI	−0.368	0.058	0.440	0.020	−0.647	0.009

表 5　不同 BMI 的 sT2DM 患者上、下肢骨骼肌质量对胰岛功能的影响

Tab. 5　Effects of upper and lower limbs skeletal muscle mass on islet function in T2DM patients with different BMIs

SMI	正常				超重				肥胖			
	上肢 SMI		下肢 SMI		上肢 SMI		下肢 SMI		上肢 SMI		下肢 SMI	
	β	P_{adj}	β	P_{adj}	β	P_{adj}	β	P_{adj}	β	P_{adj}	β	P_{adj}
胰岛功能												
HOMA-β	−0.049	0.688	0.233	0.113	0.085	0.665	−0.119	0.439	0.551	0.032	0.593	0.008
IGI	0.186	0.290	0.238	0.110	0.212	0.281	0.088	0.572	0.061	0.829	0.253	0.313
CIR	−0.131	0.286	0.273	0.063	0.249	0.213	0.081	0.600	0.413	0.120	0.446	0.056
IR 或 IS												
HOMA-IR	0.044	0.722	0.227	0.124	−0.371	0.047	−0.366	0.012	0.489	0.054	0.544	0.014
Matsuda ISI	0.001	0.996	−0.198	0.180	0.370	0.048	0.351	0.016	0.506	0.043	−0.583	0.007

3　讨　论

本研究通过分析骨骼肌含量与 T2DM 患者胰岛 β 细胞功能及胰岛素抵抗的相关性，进一步探讨了上下肢骨骼肌含量在不同内脏脂肪及 BMI 水平的 T2DM 患者中的意义，结果表明患者骨骼肌功能及含量与血糖、胰岛 β 细胞功能及胰岛素抵抗水平密切相关，且相较于上肢 SMI，下肢 SMI 水平与 T2DM 患者不同时间点血糖、胰岛素、C 肽及胰岛 β 细胞功能的相关性更显著。因此，提高下肢 SMI 水平对于改善 T2DM 患者血糖、胰岛 β 细胞功能及胰岛素抵抗具有重要意义。此外，在超重的 T2DM 亚组中，上下肢 SMI 水平提高对改善胰岛素抵抗及胰岛素敏感性具有显著作用，而在内脏脂肪超标或肥胖的 T2DM 患者中意义尚不明确。

肌肉含量尤其是骨骼肌含量对 T2DM 患者治疗及预后具有重要意义，应当早期对糖尿病患者特别是存在高风险因素的患者进行骨骼肌含量、质量及力量评估[7-8]。目前常用于骨骼肌测定评估方法包括人体测量学方法、BIA、超声法、双能 X 线骨密度法（DXA）、X 线计算机断层扫描（CT）及核磁共振扫描法（MRI）等[9-10]。上述测定方法使用场景不同且存在各自优缺点，而自 1985 年 Lukaski 首次提出使用 BIA 评估人体成分以来，其由于安全、方便、无创及经济等特点，BIA 应用受到越来越多的关注及推广[11-13]。BIA 主要根据体内低电压电流流动程度来对人体脂肪、肌肉及水分等身体成分进行无创分析及测定，适用于临床评估及快速人体成分检测[14]。目前已有多项临床研究证实了 BIA 与 DXA 及 MRI 结果的一致性及可靠性，但在部分对于精确评估要求较高的研究中仍存在一定争议[15]。

骨骼肌作为体内葡萄糖利用及能量代谢重要的组织之一，其含量对于 T2DM 患者血糖稳态维持具有重要意义[16]。胰岛素介导的葡萄糖摄取主要发生在骨骼肌内，其含量的增加可直接提高人体基础代谢率及能量消耗水平[17]。体内骨骼肌含量对于胰岛素敏感性具有重要作用，胰岛素抵抗与线粒体含量及功能密切相关，骨骼肌细胞内线粒体异常可通过增加活性氧的产生来加速胰岛素抵抗的进展[18-19]。此外，有研究报道骨骼肌细胞可通过分泌细胞因子对胰岛 β 细胞功能发挥重要调控作用，但目前具体机制尚不完全明确[20]。T2DM 患者易出现肥胖伴肌肉减少，而骨骼肌质量减少与葡萄糖代谢障碍密切相关。肌少性肥胖最早于 2000 年由 Baumgartner 等提出，即肌肉减少症与肥胖症并存，但目前仍缺乏统一的诊断标准[21]。与单纯肌肉减少症相比，肌少性肥胖与胰岛素抵抗、心血管疾病及死亡率增加显著相关[22-23]。本研究结果提示，在正常及超重状态下，提高骨骼肌含量对于改善胰岛 β 细胞功能及胰岛素抵抗具有重要作用，但在内脏脂肪超标或肥胖状态下该相关性减弱或消失。此外，与上肢 SMI 水平相比，下肢 SMI 水平与 T2DM 患者血糖及胰岛 β 细胞功能的相关性更显著。因此，提高糖尿病患者全身骨骼肌尤其是下肢骨骼肌含量及相应减少脂肪含量对于血糖稳态维持及胰岛功能改善具有重要价值。

肌肉含量、质量及功能与 T2DM 患者营养状况及整体代谢水平密切相关，包括饮食管理及运动训练等生活方式干预是预防及改善糖尿病患者胰岛功能的重要措施[24-25]。目前，不同类别降糖药物可能对 T2DM 患者肌肉含量存在一定影响，例如磺脲类、格列奈类药物、噻唑烷二酮类及二肽基肽酶Ⅳ抑制剂（DPP-4i）等药物与肌肉含量减少或质量下降存在潜在相关性[26]，因此在针对不同患者进行降糖药物及方案选择时，应当考虑患者个体差异性，选择合适的降糖方案[27-28]。此外，早期采用 BIA 等方法对 T2DM 患者肌肉含量尤其是骨骼肌质量进行测定及评估，必要时指导患者调整治疗方案或采取合适的干预及训练措施，对于 T2DM 患者血糖控制及远期并发症防治

具有重要意义。

利益冲突　无

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