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Risk and determinants of sarcopenia in people with diabetes: a case–control study from Qatar Biobank cohort

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Abstract

Background Diabetes is associated with impairments in muscle mass and quality increasing the risk of sarcopenia. Thus, this study aimed to investigate the odds of sarcopenia and its associated risk factors among Qatari adults (> 18 years), while exploring the modulating effects of health and lifestyle factors.

Methods Using a case–control design, data from 767 participants (481 cases with diabetes and 286 controls without diabetes) was collected from Qatar Biobank (QBB). Sociodemographic, lifestyle factors including dietary intake, anthropometric and biochemical measures were analyzed. Handgrip strength, Dual X-ray absorptiometry (DXA), and Bio-impedance were used to assess muscle strength, muscle mass and muscle quality, respectively. The risk of sarcopenia was estimated using the European consensus on definition and diagnosis of sarcopenia.

Results Cases with diabetes were older (55 vs. 36 years; $P < 0.001$), had higher BMI (31.6 vs. 28.3 kg/m2; $P < 0.001$), lower cardiorespiratory fitness (50.0% "Moderate" fitness for cases, 62.9% "High" fitness for controls), and consumed less total (59.0 vs. 64.0; $P = 0.004$) and animal protein (39.0 vs. 42.0; $P = 0.001$), compared to controls based on a computed score. Participants with diabetes also had lower appendicular lean mass/BMI, handgrip strength, and higher probability of sarcopenia/probable sarcopenia ($P < 0.005$). Adjusted multiple logistic regression revealed that elevated cardiorespiratory fitness (β = 0.299, 95%CI:0.12–0.74) and blood triglycerides (β = 1.475, 95% CI: 1.024–2.124), as well as being a female (β = 0.086, 95%CI: 0.026–0.288) and having higher BMI (β = 0.908, 95%CI: 0.852–0.967) and ALM/BMI (β = 0.000, 95% CI: 0.000–0.007) are independent predictors ($p < 0.05$) of sarcopenia risk.

Conclusions This study highlights the intricate relationship between diabetes and sarcopenia, revealing modifiable risk factors. Individuals with diabetes were found to have a higher likelihood of sarcopenia, which was associated with lower fitness levels and higher blood triglycerides. Protective factors against sarcopenia included being female and having higher BMI and ALM/BMI ratios.

Keywords Diabetes, Sarcopenia, Appendicular lean mass, BMI, Cardiorespiratory fitness, Protein intake

Background

Over the last few decades, the prevalence of diabetes has been significantly increasing globally [1]. According to the International Diabetes Federation, in 2019, the Middle East and North African (MENA) region had the highest age-adjusted prevalence of diabetes in people aged 20–79 years [2]. In addition to a genetic predisposition,

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obesity, physical inactivity, urbanization, and poor nutritional habits have been implicated as primary risk factors for diabetes and prediabetes in this region [3]. In Qatar, diabetes prevalence is considered one of the highest in the MENA region, especially among the adult Qatari population, with the highest prevalence reported among the 40–49 years age group (31.2%), with a notable gender disparity, whereby 53.3% of Qatari women have diabetes compared to 46.8% of Qatari men [4].

People with diabetes must manage multiple factors including dietary changes, medication adherence, and prevention and management of potential complications. This burden of self-management can lead to a lower quality of life [5]. In recent years, sarcopenia has emerged as an additional complication that people with diabetes are at increased risk of developing [6, 7]. Having a high HbA1c, prediabetes, diabetes, and suffering from diabetes complications were all significantly associated with sarcopenia [8]. Additionally, having a lower Body Mass Index (BMI) or an older age also increased the risk of sarcopenia [6].

Sarcopenia has been defined by the European Working Group on Sarcopenia in Older People as a disease of the muscles or as muscle failure caused by changes that accumulate with age [9]. Sarcopenia is associated with numerous adverse physical and mental health outcomes, including cognitive impairment, functional decline, depression, falls and fractures, and increased mortality. Sarcopenia leads to difficulties in performing activities of daily living, which increases to risk of disability and thus impacts quality of life [10–12].

The relationship between type 2 diabetes and sarcopenia is bidirectional, meaning that the presence of one can increase the risk of developing the other. Multiple factors including insulin resistance, inflammation, oxidative stress, and vascular complications, contribute to muscle health. Poor muscle health, in turn, can also lead to the development and progression of type 2 diabetes [13]. Genetic factors also seem to play a role in this relationship; a recent study identified 15 common genes that are correlated with both type 2 diabetes and sarcopenia, suggesting that the two conditions share a similar pathogenesis [14].

Various modifiable risk factors have been reported to modulate the risk of sarcopenia such as diet, physical activity, body composition and biochemical characteristics [15]. In specific, the role of dietary protein intake with or without physical activity, in improving muscle mass and strength and lowering the risk of sarcopenia has been established in the older population [16–18]. However, studies on people with diabetes are limited, despite increased attention to this topic in recent publications. This is particularly relevant for studies involving Middle Eastern participants. Understanding the risk factors of sarcopenia among individuals with diabetes can guide healthcare practitioners in clinical settings to identify, prevent or address sarcopenia at an early stage.

Therefore, the aim of this study is to investigate the odds of sarcopenia and its associated risk factors among people with diabetes in the Qatari population.

Methods

Study population

This was a case–control study with a total sample size of 767 participants, 481 cases diagnosed with diabetes mellitus (DM), and 286 controls without DM. Based on the formula proposed by Kelsey et al. (1996) for unmatched case–control studies, a minimum total sample size of 240 participants (80 controls and 160 cases) is required. This calculation assumes 80% power and a 95% confidence interval. Therefore, our sample size of 767 participants exceeds this minimum requirement [19, 20]. Data were provided by Qatar Biobank (QBB), a platform that collects demographics, health, and lifestyle information from a representative sample of participants from the Qatari population [21]. In this study, cases were comprised of adult men and women (≥18 years old) with diabetes, while controls were healthy individuals. Exclusion criteria for both groups were the presence of a terminating illness (such as cancer or end-stage renal disease), pregnancy, being an athlete, or taking medications that affect muscle mass such as glucocorticoids. Demographic characteristics, lifestyle factors including dietary intake, anthropometric measurements, and biochemical data were retrieved and analyzed. Data were collected by trained medical staff at the QBB clinics/hospitals, whereby details of the study design and data collection has been previously published [21]. The ethical approval for the overarching study protocol for the larger QBB cohort was obtained from the Hamad Medical Corporation Ethics Committee in 2011 and continued with the QBB Institutional Review Board (IRB) from 2017 onward. It is renewed on an annual basis. The current study was granted exemption review by QBB IRB under approval number Ex-2022-QF-QBB-RES-ACC-0101–209. Informed consent was obtained from all subjects involved in this study.

Sociodemographic and lifestyle characteristics

Age, gender, education, income, and smoking were retrieved from the Qatar Biobank data. Age was presented both as a continuous and categorical variable (≤35; 36–60; >60 years), while gender (Male; Female), education level (high school and below; technical/university degree and above), income per month (below 20,000; above 20,000 QR; I don't know/no income) and smoking

(non-smoker; smoker) were reported as categorical variables.

Dietary measurements

Dietary intake was assessed using a qualitative food frequency questionnaire (FFQ). The FFQ was pre-tested for its internal validation before used in the study [21]. The FFQ included 96 food and beverage items consumed by Qatari population with 6 frequency options (Never,1–3 times/month, 1–3 times/week, 4–6 times/week, once/day and 2 or more/day) [21]. To assess protein intake only, food items containing 7 g or more of protein per 100 g were included (all food groups except fruits and vegetables). A total of 57 food items were included (39 were grouped as animal protein sources and 18 were grouped as plant protein sources) (Supplementary file). Based on the consumption frequency, scores were assigned for each food item included in the analysis ranging from zero to five points (Never = 0, 1–3 times/month = 1, 1–3 times/week = 3, 4–6 times/week = 4, once/day and 2 or more/day = 5). The score of all the 57 food items was added, resulting in a maximum score for total protein intake of 285 (total animal protein max score of 195, and total plant protein maximum score of 90). Thus, the higher value of the scores reflects higher protein intake.

Anthropometrics handgrip strength and cardiorespiratory fitness

Anthropometric measures including weight (kg) and height (cm) were collected using Seca stadiometer. Body mass index (BMI) was computed from weight (Kg) divided by height^2 (m^2) and presented as both continuous and categorical (underweight; normal; overweight; obese). Bio-impedance (Tanita) was used to assess muscle mass and quality, while dual energy X-ray absorptiometry (iDXA) scans were used to assess body composition. In addition, handgrip strength was measured using hydraulic hand dynamometer (Jamar J00105) and was used to assess muscle strength. Cardiorespiratory fitness was assessed using a graded treadmill test lasting 5 to 11 min, tailored to the participant's self-rated fitness, using the h/p/cosmos quasar treadmill. Heart rate monitoring during the test measured the efficiency of oxygen delivery by the heart and lungs during exercise [21, 22].

Sarcopenia diagnosis

Probable sarcopenia was diagnosed based on the presence of low muscle strength only, whereas sarcopenia diagnosis was based on both low muscle strength and low muscle quantity/mass [9]. Muscle strength was assessed using handgrip strength, as aforementioned. According to the European consensus on the definition and diagnosis of sarcopenia, low muscle strength is defined as handgrip strength below 27 kg for men and below 16 kg for women. Low muscle quantity/mass was assessed using the appendicular lean mass (ALM) divided by height squared (ALM/height^2), where appendicular lean mass is the sum of the lean mass in the arms and legs assessed using bioimpedance, as aforementioned. The European consensus cutoffs for low muscle mass are less than 7.0 kg/m^2 for men and less than 5.5 kg/m^2 for women.

Biochemical measurements

Various biochemical tests were conducted to assess serum levels including Total Protein (g/L), Albumin (g/L) and C-reactive protein (CRP). CRP levels were categorized as < 5 mg/L (normal) and ≥ 5 mg/L. Cholesterol Total (mmol/L), HDL-Cholesterol (mmol/L), LDL-Cholesterol Calc (mmol/L), and Triglyceride (mmol/L) levels were also reported. Dihydroxy vitamin D Total (ng/mL) levels were measured to evaluate vitamin D status. Insulin (mcunit/mL), Glucose (mmol/L), and HBA1C (%) levels were measured to gain insights into glucose metabolism and glycemic control.

Statistical analysis

Data analysis was performed using the Statistical Package for Social Sciences (SPSS, version 25). Descriptive statistics were reported as median and interquartile ranges (for continuous, non-normally distributed variables) and as frequencies (n) and proportion (%) (for categorical variables). Normality of the variables were evaluated using the Shapiro–Wilk test of normality. Mann–Whitney U tests were used to chart comparisons for non-normal continuous variables. Simple and multiple logistic regression analysis were conducted to explore the associations of sociodemographic, lifestyle, dietary and biochemical characteristics of the study sample with the odds of sarcopenia and probably sarcopenia combined. All variables identified as significant in the simple logistic models were included as independent variables in the final multiple logistic regression models. These variables included Age, Gender, Smoking, BMI, Diabetes Diagnosis, Cardiorespiratory Fitness, Participant Distribution Plant Protein Score Tertile, Albumin (g/L), CRP (mg/L), LDL-Cholesterol (Calc, mmol/L), Triglyceride (mmol/L), Dihydroxy Vitamin D Total (ng/mL), Glucose (mmol/L), HbA1c (%), Visceral Fat (Android Fat), ALM/BMI, and Phase Angle. Results from the logistic regression analyses were expressed as β (95% CI) or adjusted β (95% CI). A p-value < 0.05 was considered statistically significant.

Results

The socio-demographic and lifestyle variables of the study participants are summarized in Table 1. The final study sample consisted of 481 cases diagnosed with diabetes mellitus (DM), and 286 controls without DM. The median age of the total sample was 49.0 years (IQR 22), with a significant difference observed between participants with DM (median 55.0 years, IQR 14) and controls (median 36.0 years, IQR 19) (*P < 0.001*). While gender distribution showed no significant difference between groups, controls without DM had higher education level (*P < 0.001*). Participants with a technical/university degree and above were more frequently controls (53.1%) than cases with DM (38.7%). Additionally, smoking rates were lower among participants with DM (12.1%) than controls (18.2%), while cardiorespiratory fitness was lower in cases with DM. More participants with DM were in the "Moderate" fitness category (50.0%),

Table 1 Sociodemographic and lifestyle characteristics

Socio-demographic and lifestyle variables n (%)	Total (*n* = 767)	Participants with DM (*n* = 481)	Participants without DM (n = 286)	*p-value*[a]
Age (years)	49.0(22)	55.0(14)	36.0(19)	***P < 0.001***
Age categories (years)				
≤ 35 years old	175(22.8)	42(8.7)	133(46.5)	$X^2 = 164.38$ ***P < 0.001***
36–60	444(57.9)	307(63.8)	137(47.9)	
> 60	148(19.3)	132(27.4)	16(5.6)	
Gender				
Male	337(43.9)	221(45.9)	116(40.6)	$X^2 = 2.113$ ***P = 0.146***
Female	430(56.1)	260(54.1)	170(59.4)	
Education level				
High school and below	429(55.9)	295(61.3)	134(46.9)	$X^2 = 15.252$ ***P < 0.001***
Technical/University degree and above	338(44.1)	186(38.7)	152(53.1)	
Total income per month (Q.R.)				
Below 20,000	306(39.9)	210(43.7)	96(33.6)	$X^2 = 8.951$ ***P = 0.011***
Above 20,000	314(40.9)	179(37.2)	135(47.2)	
I don't know/no income	147(19.2)	92(19.1)	55(19.2)	
Smoking				
Non-smoker	657(85.7)	423(87.9)	234(81.8)	$X^2 = 5.475$ ***P = 0.019***
Smoker	110(14.3)	58(12.1)	52(18.2)	
Cardiorespiratory fitness				
Low	87(12.8)	76(18.7)	11(4.0)	$X^2 = 75.892$ ***P < 0.001***
Moderate	294(43.2)	203(50.0)	91(33.1)	
High	300(44.1)	127(31.3)	173(62.9)	
BMI (kg/m^2)	30.4(7.87)	31.6(7.56)	28.3(8.45)	***P < 0.001***
BMI categories (kg/m^2)				
Underweight (< 18.5)	8(1)	0(0)	8(2.8)	$X^2 = 60.174$ ***P < 0.001***
Normal (18.5–24.9)	100(13.1)	35(7.3)	65(22.8)	
Overweight (25.0–29.9)	249(32.5)	153(31.9)	96(33.7)	
Obese (≥ 30)	408(53.3)	292(60.8)	116(40.7)	
Sarcopenia diagnosis				
No sarcopenia	612(88.1)	360(83.1)	252(92.2)	$X^2 = 27.405$ ***P = < 0.001***
Probable sarcopenia	71(10.2)	64(14.8)	7(2.7)	
Diagnosed sarcopenia	12(1.7)	9(2.1)	3(1.1)	

Continues variables reported as median (IQR) and Categorical variable reported as n(%)

Sarcopenia diagnosed as handgrip strength (Low muscle quantity/mass): < 27 kg men, < 16 kg Women, and muscle mass defined as ASM/ht^2 < 7 kg/m^2 men and < 5.5 kg/m^2 women. Probable sarcopenia diagnosed only as handgrip strength: < 27 kg men, < 16 kg Women

DM Diabetes Mellitus, *BMI* Body mass index (kg/m^2), *Q.R.* Qatar Riyal, Non-smoker including never smoker and past smokers

[a] *p*-value was derived from chi-square for categorical variables and from Mann Whitney U test t for continuous variables

while controls without DM predominantly fell into the "High" fitness category (62.9%). Furthermore, cases with DM had a significantly higher BMI (31.6 kg/m^2, IQR 7.56) than controls (28.3 kg/m^2, IQR 8.45), with higher prevalence of participants with obesity (60.8% vs. 40.7%) among participants with DM *(P < 0.001)*. In addition, a significant difference was found between groups for sarcopenia diagnosis (*P < 0.001*). Participants with DM had higher rates of "Probable sarcopenia" (14.8%) and "Diagnosed sarcopenia" (2.1%) compared to controls without DM, where "Probable sarcopenia" was 2.7%, and "Diagnosed sarcopenia" was 1.1%.

As depicted in Fig. 1, controls without DM exhibited a notably higher median total protein score (64.0, IQR 33.0) compared to Participants with DM (59.0, IQR 28.0) (*P* = 0.004), and a higher median animal protein score (42.0, IQR 22.0) compared to cases with DM (39.0, IQR 18.0) (*P = 0.001*). On the contrary, there was no significant difference in plant protein scores between groups (*P = 0.115*). Consistently, when divided into tertiles, significant differences were observed in the third tertiles for both total protein scores (*P* = 0.023) and animal protein scores (*P* = 0.026), with controls without DM having higher scores compared to cases with DM. On the other hand, the plant protein score did not exhibit significant differences between groups in any of the tertiles.

Biochemical characteristics, as presented in Table 2, revealed significant differences (*P* < 0.001) in all measured parameters, except for total protein (g/L), where both groups had similar median levels (74.0 g/L) with an IQR of 5 g/L). Controls without DM had significantly higher levels of albumin (44.0 g/L, IQR 4.0) compared to cases with DM (41.0 g/L, IQR 5.9). Additionally participants with DM were found to have significantly higher levels of triglycerides (1.5 mmol/L, IQR 1.0), dihydroxy vitamin D (22.0 ng/mL, IQR 12), insulin (14.5 mcunit/ml, IQR 14.7), glucose (8.5 mmol/L, IQR 4.4), and HbA1C (7.9%, IQR 1.9) compared to controls without DM, while the latter had higher levels of total cholesterol (5.0 mmol/L, IQR 1.1), HDL-cholesterol (1.3 mmol/L, IQR 0.52), and LDL-cholesterol (3.0 mmol/L, IQR 1.04). Furthermore, cases with DM had a higher percentage of individuals with elevated CRP levels (> 5 mg/L) compared to controls without DM (45.1% vs. 32.3%).

Figure 2 presents body composition measurements stratified by sex and group. In general, cases with DM had higher total fat-free mass (TFFM), trunk fat mass (Trunk FM), android fat mass (AFM) compared to controls

Fig. 1 Total, animal and plant dietary protein intake. Y axis = Median, Error bar = IQR. Case: Participants with Diabetes Mellitus; Control: Participants without Diabetes Mellitus. * Significant differences ($p < 0.05$) between cases and controls

Table 2 Biochemical characteristics

Biochemical measurements	Median (IQR)			
	Total (*n*=767)	**Participants with DM (*n*=481)**	**Participants without DM(*n*=286)**	***p*-value**
Total Protein g/L	74.0(5)	74.0(5)	73.5(5)	0.593
Albumin g/L	43.0(5.8)	41.0(5.9)	44.0(4.0)	**<0.001**
CRP mg/L				
<5	456(59.7)	263(54.9)	193(67.7)	**X^2=12.192**
≥5	308(40.3)	216(45.1)	92(32.3)	**P^a=<0.001**
Cholesterol Total mmol/L	4.7(1.4)	4.6(1.6)	5.0(1.1)	**<0.001**
HDL-Cholesterol mmol/L	1.3(0.45)	1.2(0.5)	1.3(0.52)	**<0.001**
LDL-Cholesterol Calc mmol/L	2.7(1.32)	2.5(1.4)	3.0(1.04)	**<0.001**
Triglyceride mmol/L	1.3(1.0)	1.5(1.0)	1.1(0.7)	**<0.001**
Dihydroxy vitamin D Total ng/mL	19.0(12)	22.0(12)	16.0(11)	**<0.001**
Insulin mcunit/ml	12.1(11.5)	14.5(14.7)	9.9(6.8)	**<0.001**
Glucose mmol/L	6.6(4.4)	8.5(4.4)	4.9(0.7)	**<0.001**
HBA1C %	7(2.9)	7.9(1.9)	5.3(0.5)	**<0.001**

Difference between groups were examined using Mann–Whitney U test

DM Diabetes Mellitus, *CRP* C-Reactive Protein, *HBA1C* Glycated Hemoglobin

[a] *p*-value was derived from chi-square for categorical variables

without DM, while the latter exhibited higher handgrip strength, phase angle, and appendicular lean mas/BMI (ALM/BMI). Among women, significant differences were observed in TFFM, Trunk FM, AFM, handgrip strength (right), phase angle, and ALM/BMI between groups ($P<0.001$). Similarly, among men, significant differences were found in Trunk FM, AFM, handgrip strength (right), phase angle, and ALM/BMI between participants with and without DM ($P<0.001$), with the exception of TFFM ($P=0.223$).

Table 3 shows the associations between sociodemographic, lifestyle, dietary and biochemical characteristics of the study sample with the odds of sarcopenia and probable sarcopenia. Unadjusted simple regression models revealed that higher odds of sarcopenia/probable sarcopenia were associated with age, having diabetes, higher levels of CRP (≥5 mg/L), triglycerides, vitamin D, glucose and HBA1C level. On the other hand, lower odds were associated with high cardiorespiratory fitness, total, animal and plant protein intake, albumin, LDL-cholesterol and ALM/BMI. In the fully adjusted model, gender, BMI, fitness levels, ALM/BMI and triglycerides were found to be independently and significantly associated with the risk of sarcopenia. Females had significantly lower odds of sarcopenia compared to males (β=0.086, 95% CI: 0.026, 0.288, $P<0.001$), while higher BMI was associated with lower odds of sarcopenia (Adjusted β=0.908, 95% CI: 0.852 to 0.967, $P=0.003$). Additionally, participants with high fitness levels (β=0.158, 95% CI: 0.076 to 0.327, $P<0.001$) and higher ALM/BMI (β=0.000, 95% CI: 0.000, 0.007, $P<0.001$) had lower odds of sarcopenia. However, elevated blood triglycerides were associated with higher odds of sarcopenia (β=1.475, 95% CI: 1.024, 2.124, $P=0.037$).

Discussion

In the present study, the prevalence of probable sarcopenia and sarcopenia was found to be higher among people with diabetes (17%) as compared to their healthy counterparts (4%). These findings are consistent with the literature. For example, a meta-analysis of global studies found that the prevalence of sarcopenia in people with diabetes was 31.1% [23], while a meta-analysis in the Asian population showed that the risk for sarcopenia was prevalent in 15.9% of patients with diabetes [24]. This association between diabetes and sarcopenia has been attributed to multiple genetic and pathophysiological factors such as insulin resistance, inflammation, increased oxidation, micro and macrovascular complications, along with lifestyle factors such as physical activity and diet that have also been implicated [13–15].

Among the demographic and lifestyle characteristics, participants with DM in the present study were significantly older, less physically active, more likely to have an elevated BMI, less educated and they consumed less overall protein and animal protein as compared to subjects in the control group, all of which could be contributing factors for higher risk of sarcopenia [25]. However, based on the adjusted regression model used, only having a higher BMI, better cardiorespiratory

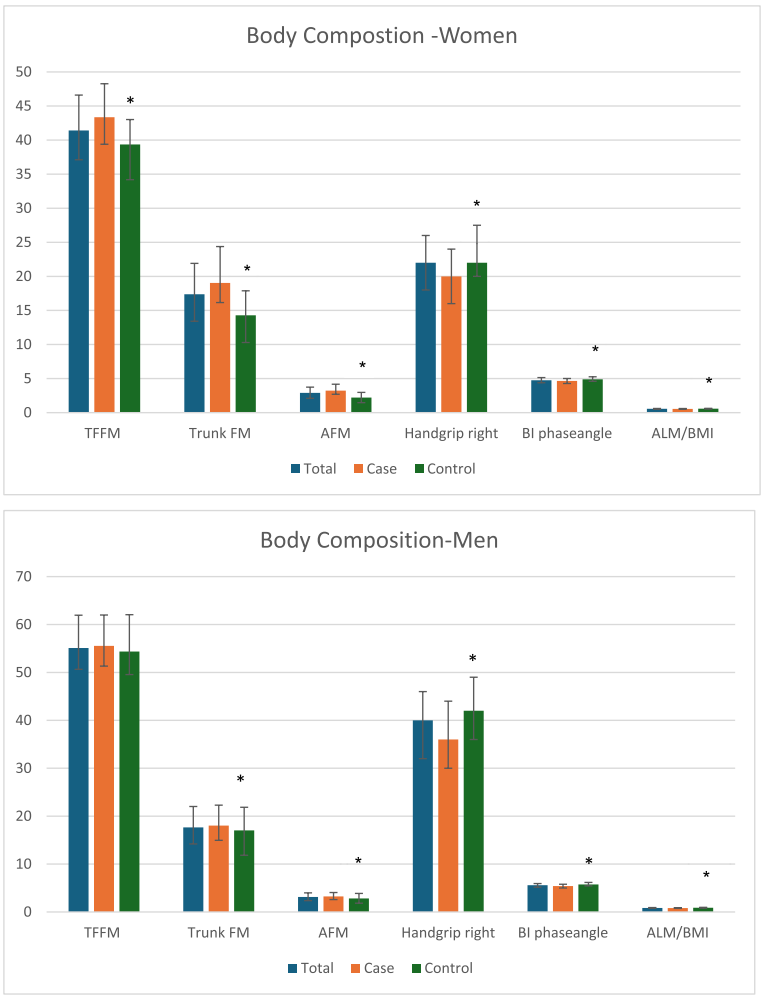

Fig. 2 Body composition stratified by sex. TFFM, total fat free mass; Trunk FM, trunk fat mass; AFM, android fat mass = visceral fat mass: ALM, appendicular lean mass (computed by adding arms lean mass and legs lean mass). Y axis = Median, Error bar = IQR. Case: Participants with Diabetes Mellitus; Control: Participants without Diabetes Mellitus. * Significant differences between cases and controls

fitness, higher ALM/BMI and being a female decreased the odds of sarcopenia. On the other hand, having elevated triglyceride levels increased the odds of sarcopenia. Elevated BMI and lean mass have been previously shown to protect against sarcopenia, while higher triglycerides levels have been associated with increased odds of sarcopenia [26]. Similarly, exercise and higher respiratory fitness have been consistently reported to be inversely associated with the risk of sarcopenia in the general population [27]. As for the finding on the protective effect of the female gender, it contradicts previous studies in the general older population where sarcopenia was more prevalent among women [26, 27]. Nevertheless, research and a meta-analysis on people with diabetes revealed lower risk of sarcopenia among women versus men, in line with our results [28, 29]. The exact mechanisms underlying the gender effect and the potential role of sex hormones on the risk of sarcopenia within the context of diabetes remain to be determined.

Our findings have important clinical implications whereby interventions targeting physical activity, aimed to improve skeletal muscle mass, may play an important role as mediators in the management and prevention of sarcopenia. A randomized controlled trial showed that a combination of resistance and aerobic trainings can attenuate metabolic syndrome and sarcopenic obesity [30]. Intensive lifestyle interventions that include physical activity and dietary supplementation of whey protein also have the potential to significantly improve muscle mass and reduce inflammation [31]. However, even small interventions such as the use of sandbags at home, showed a positive impact on skeletal muscle mass and glycosylated hemoglobin after 12 weeks [32].

Table 3 Simple and adjusted logistic regressions and odds of sarcopenia/ probable sarcopenia

	Non-adjusted β (95% CI)	*P*-value	Adjusted β (95% CI)	*P*-value
Age	1.056(1.036,1.076)	**< 0.001**	0.995(0.966,1.025)	0.751
Age (categorical)				
≤ 35 years old	Ref		-	
36–60	1.661(0.809,3.411)	0.167	-	
> 60	5.667(2.675,12.002)	**< 0.001**	-	
Gender				
Male	Ref		Ref	
Female	1.312(0.822,2.094)	0.255	0.086(0.026,0.288)	**< 0.001**
Smoking				
No	Ref		Ref	
Yes	0.588(0.275,1.259)	0.171	1.206(0.463,3.147)	0.702
BMI	1.017(0.981,1.055)	0.347	0.908(0.852,0.967)	**0.003**
Diabetes diagnosis				
Participants without DM (Controls)	Ref		Ref	
Participants with DM (Cases)	5.110(2.588,10.089)	**< 0.001**	1.489(0.466,4.758)	0.501
Cardiorespiratory fitness				
Low	Ref		Ref	
Moderate	0.365(0.192,0.693)	**0.002**	0.551(0.255,1.193)	0.131
High	0.158(0.076,0.327)	**< 0.001**	0.337(0.129,0.880)	**0.026**
Total protein score	0.987(0.976,0.997)	**0.016**	-	
Animal protein score	0.982(0.967,0.997)	**0.021**	-	
Plant protein score	0.969(0.942,0.997)	**0.028**	-	
Participants distribution total protein score tertile				
1st tertile	Ref		-	
2nd tertile	0.796(0.466, 1.359)	0.403	-	
3rd tertile	0.516(0.288,0.924)	**0.026**	-	
Participants distribution animal protein score tertile				
1st tertile	Ref		-	
2nd tertile	0.938(0.549,1.604)	0.816	-	
3rd tertile	0.585(0.342,1.056)	0.075	-	
Participants distribution plant protein score tertile				
1st tertile	Ref		Ref	
2nd tertile	1.015(0.605,1.703)	0.955	0.776 (0.394,1.530)	0.464
3rd tertile	0.462(0.246,0.865)	**0.016**	0.502(0.235,1.074)	0.076
Total Protein g/L	0.982(0.982,1.039)	0.533	-	
Albumin g/L	0.892(0.841,0.947)	**< 0.001**	0.935(0.861,1.015)	0.110
CRP mg/L				
< **5**	Ref		Ref	
≥ **5**	1.619(1.022,2.565)	**0.040**	0.917(0.469,3.224)	0.800
Cholesterol Total mmol/L	0.835(0.662,1.054)	0.129	-	
HDL-Cholesterol mmol/L	1.028(0.537,1.969)	0.934	-	
LDL-Cholesterol Calc mmol/L	0.648(0.491,0.854)	**0.002**	0.728(0.517,1.025)	0.069
Triglyceride mmol/L	1.413(1.117,1.786)	**0.004**	1.475(1.024,2.124**)**	**0.037**
Dihydroxy vitamin D Total ng/mL	1.030(1.008,1.052)	**0.006**	1.013(0.981,1.046)	0.441
Insulin mcunit/ml	1.006(0.999,1.013)	0.098	-	
Glucose mmol/L	1.159(1.102,1.220)	**< 0.001**	1.088(0.972,1.218)	0.141
HBA1C %	1.276(1.152,1.414)	**< 0.001**	1.001(0.766,1.307)	0.994
Total Fat Mass	1.007(0.988,1.027)	0.456	-	
Trunk FM	1.012(0.981,1.045)	0.488	-	

Table 3 (continued)

	Non-adjusted β (95% CI)	*P*-value	Adjusted β (95% CI)	*P*-value
Visceral fat (android fat)	1.117(0.942,1.324)	0.203	-	
ALM/BMI	0.035(0.007, 0.167)	**< 0.001**	0.000(0.000, 0.007)	**< 0.001**
Phase angle	0.389(0.274,0.553)	**< 0.001**	0.714(0.384,1.328)	0.287

Simple and fully adjusted logistic regression analyses to explore the associations with the odds of sarcopenia/probable sarcopenia. Variables found significant in the simple logistic models were entered in the multiple logistic regression model as independent variables

DM Diabetes Mellitus, *BMI* Body Mass Index, *CRP* C-Reactive Protein, *HBA1C* Glycated Hemoglobin, *Trunk FM*, Trunk fat mass, *ALM* Appendicular lean mass (*computed by adding arms lean mass and legs lean mass)

Results are expressed as β (95% CI). *p*-value < 0.05 was considered statistically significant

Although in this study we did not detect a role for protein intake in the prevention of sarcopenia, providing adequate protein and energy intakes was shown to support higher skeletal muscle mass and strength [33]. Multiple studies providing protein intakes around 1.0–1.3 g/kg body weight, especially from high biological value sources, along with an adequate energy intake showed improvements in muscle mass, muscle strength and inflammatory markers [33–35]. A limitation in this study was the use of a qualitative food frequency questionnaire as it was the only tool used by the Qatar Biobank to assess dietary intake, thus it did not allow for the proper quantitative assessment of protein and energy intakes. Although qualitative FFQs are not designed to provide precise quantitative estimates, they are effective at capturing general dietary patterns and the frequency of food consumption in large-scale population studies, especially when they include an extensive list of items [36]. This approach allowed us to categorize participants' protein intake. Tertiles of consumption were computed, and the results showed that subjects in the control group without DM consumed significantly more overall and animal protein, and a higher number of subjects in the control group consumed protein in the highest tertiles for protein. Additionally, in the univariate analysis, intakes of total, animal and protein were significantly associated with lower risk of sarcopenia. However, in the adjusted regression model, protein intake lost its significance, which is likely attributed to the qualitative nature of the available data for protein intake. Future studies should consider the use of quantitative food frequency questionnaires or food records to quantify protein intake accurately.

To our best knowledge, this is the first study to assess sarcopenia in a Qatari population with diabetes. Given the high prevalence of diabetes and the lifestyle characteristics of this population, these findings can support practitioners in providing interventions tailored to prevent and manage sarcopenia among persons with diabetes. Although generally, sedentary lifestyles and unhealthy eating habits are common in Qatar [37, 38], people with diabetes tend to have better adherence and attitudes toward dietary guidelines and physical activity [39, 40]. Women and older persons, specifically, tend to be less physically active as compared to younger subjects and men [37]. There are many barriers and challenges to engaging people with sarcopenia and diabetes in more physical activity and they include fear, financial constraints, physical and psychological discomfort among others [41]; and these should be further explored in the Qatari population to ensure that adaptation is made to the cultural context. However, despite the challenges, promoting physical activity interventions at the individual level and national levels should be among the priorities.

Given that this is a cross-sectional study, it doesn't capture variable changes over time. Thus, a longitudinal study would have offered better insight into the causal relationships between the variables and sarcopenia. Future research should focus on longitudinal, interventional studies investigating the type, duration and intensity of physical activity that is feasible and beneficial while exploring the facilitators and barriers to physical activity in this specific population. Lastly, more studies exploring the role of dietary proteins and other dietary factors should be performed using quantitative assessment tools.

Conclusions

In conclusion, the present study is the first to investigate the impact of diabetes on muscle mass and function and risk of sarcopenia in Qatari adults, while exploring the potential modulating effects of diet and lifestyle factors such as physical activity and protein intake. Cases with diabetes were more likely to be at risk of or suffer from sarcopenia; they were less physically active, and they consumed less overall and animal protein. Being a woman, having better fitness level, higher BMI and ALM/BMI were protective factors against sarcopenia in the general population.

Abbreviations

MENA	Middle East and North Africa
BMI	Body Mass Index
QBB	Qatar Biobank
IRB	Institutional Review Board
FFQ	Food Frequency Questionnaire
DM	Diabetes Mellitus
TFFM	Total Fat-Free Mass
Trunk	FM Trunk Fat Mass
AFM	Android Fat Mass
ALM	Appendicular Lean Mass

Supplementary Information

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Supplementary Material 1.

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Authors' contributions
H.S.: Data analysis, results interpretation, and editing the manuscript. N.G., G.B., and S.A.Z.: Drafting the initial manuscript. C.F.E: Study design, results interpretation, and editing the manuscript. M.B.: Study design, results interpretation, editing and finalizing the manuscript. All authors critically reviewed and approved the final version of the manuscript.

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Availability of data and materials
The data presented in this study may be available on request from Qatar Biobank.

Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The ethical approval for the overarching study protocol for the larger Qatar Biobank (QBB) cohort was obtained from the Hamad Medical Corporation Ethics Committee in 2011 and continued with the QBB Institutional Review Board (IRB) from 2017 onward. It is renewed on an annual basis. QBB data collection is in compliance with the Helsinki Declaration and utilized deidentified information from adults visiting the Qatar Biobank clinics. Informed consent was obtained from all subjects involved in the study. Study protocol for the access to QBB data for the current study was submitted to, and reviewed by, the Qatar Biobank Institutional Review Board (QBB IRB) in Qatar, which granted an exemption review under approval number Ex-2022-QF-QBB-RES-ACC-0101–209.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

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