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Dietary influence on the link between depression and muscle mass and muscle strength: exploring interaction and mediation effects

Da Gan[1†], Xuebiao Wu[2†], Yingjuan Zhang[3,4], Yue Gao[3,4], Xia Huang[1*] and Shuang Han[3,4*]

Abstract

Introduction The present study aimed to investigate the associations of depression with muscle mass and muscle strength, and whether these associations were modified or mediated by dietary energy intake and dietary quality.

Methods Our study included participants aged 40 and above from the 2011–2018 cycles of the National Health and Nutrition Examination Survey (NHANES). Depression was evaluated using the nine-item Patient Health Questionnaire. Skeletal muscle mass index (SMI) and handgrip strength (HGS) were used to evaluate muscle mass and muscle strength, respectively. Information on dietary intake were obtained via dietary recall. Dietary quality was assessed using healthy eating index-2015 (HEI-2015). We performed multivariable linear regression models to examine the associations of depression with SMI ($N=3,648$) and HGS ($N=4,679$). Interaction analyses and mediation analyses were conducted to test the effect of dietary energy intake and HEI-2015 on the associations of depression with SMI and HGS.

Results Depression was associated with decreased SMI and HGS. Interactions between depression and HEI-2015 were observed for SMI, but not for HGS. The stratified analyses showed that depression was associated with decreased SMI in participants whose HEI-2015 were lower than the median. Mediation analyses revealed that dietary energy intake mediated the associations of depression with SMI and HGS.

Conclusion HEI-2015 modified the associations between depression and muscle mass. The inverse associations of depression with muscle mass and muscle strength were partially mediated by dietary energy intake. These findings emphasized the importance of dietary energy intake and dietary quality in preventing muscle loss in middle-aged and older participants with depression.

Keywords Depression, Muscle mass, Muscle strength, Dietary energy intake, Healthy eating index-2015, Sarcopenia

[†]Da Gan and Xuebiao Wu contributed equally to this work.

*Correspondence:
Xia Huang
yfyhuangxia@163.com
Shuang Han
hanshuang@zju.edu.cn

Full list of author information is available at the end of the article

Introduction

As the largest organ in the body, skeletal muscle plays an important role in locomotion and systemic energy metabolism [1, 2]. The progressive decline of skeletal muscle could result in the occurrence of sarcopenia, which was closely related to the increased risk of falls, physical disability, and mortality [3, 4]. Given that skeletal muscle mass and strength start to decline from 40 years of age [5–9], adopting effective intervention during middle age might be helpful in slowing the progression of muscle mass and strength loss.

Depression is a common psychiatric disorder, affecting 5.0% adults in the world [10]. Due to urbanization, the changing population structure, and the pandemic of coronavirus disease 2019, the prevalence of depression is further increasing [11–13]. Depression was reported to increase the risk of adverse events, including cardiovascular disease, disability, and mortality [10, 14, 15].

Depression and muscle wasting shared several common pathophysiological pathways, such as downregulation of neurotrophins, upregulation of oxidative stress and inflammatory markers, physical inactivity, and inadequate nutrition intake, suggesting that depression might link to the loss of muscle mass and muscle strength (16–17). Previous studies have explored the associations of depression with muscle mass and muscle strength, but the results have been inconsistent [17–21]. Some studies have reported an inverse association between depression and muscle mass and muscle strength [18, 19], while others have not observed such associations [20, 21].

Additionally, some studies have shown that gender modified the association between depression and muscle mass, interactions existed between depression and walking pace for muscle strength, and dietary inflammatory potential mediated the associations between depression and both muscle mass and muscle strength [22–24]. However, the moderating or mediating role of dietary energy intake and dietary quality in the associations of depression with muscle mass and muscle strength remained unclear.

Therefore, our study aimed to investigate the associations of depression with muscle mass and muscle strength, and whether these associations were modified or mediated by dietary energy intake and dietary quality.

Methods

Study participants

Participants were selected from the National Health and Nutrition Examination Survey (NHANES). The NHANES is an ongoing survey, which aiming to evaluate the health and nutritional status of the non-institutionalized U.S. civilian. To collect nationally representative data, the NHANES conducted a complex, multistage, probability cluster sampling design [25]. Since evidences suggested that the decline of skeletal muscle mass and muscle strength started near the 40th life year [5–9], the present study selected participants aged 40 and above from the 2011–2018 cycles of NHANES.

Outcomes in this study were muscle mass and muscle strength. Because muscle mass and muscle strength were measured in different NHANES survey cycles and subsamples, analyses of this study were performed in two distinct datasets. In the survey cycles of 2011–2018, muscle mass was measured in participants aged between 40 and 59 (muscle mass dataset). Muscle strength was measured in participants aged 40 and above (muscle strength dataset) from the 2011–2014 survey cycles.

The NHANES procedures and protocols were approved by the National Center for Health Statistics Research Ethics Review Board. All participants provided the written informed consent before involving in this survey [25]. The details about NHANES could be found on the website: https://www.cdc.gov/nchs/nhanes/index.htm.

Participant eligibility

The details about the inclusion and exclusion of participants in this study were described in Fig. 1. The muscle mass dataset selected 7,383 participants aged between 40 and 59 from NHANES 2011–2018. After excluding participants with missing data in depression ($N=1,047$), SMI ($N=1,356$), diet ($N=710$), and covariates ($N=549$), and participants with extreme data in dietary energy intake (men: < 700 kcal/day or > 4500 kcal/day, women: < 500 kcal/day or > 3500 kcal/day; $N=69$) and BMI (> 60 kg/m^2 or < 15 kg/m^2; $N=4$), a total of 3,648 participants were included in the analytic sample.

The muscle strength dataset selected 7,418 participants aged 40 and above from NHANES 2011–2014. Similar to muscle mass dataset, we excluded participants with missing data in depression ($N=1,039$), HGS ($N=590$), diet ($N=720$), and covariates ($N=610$), and participants with extreme data in dietary energy intake (men: < 700 kcal/day or > 4500 kcal/day, women: < 500 kcal/day or > 3500 kcal/day; $N=68$) and BMI (> 60 kg/m^2 or < 15 kg/m^2; $N=12$), resulting in an analytic sample of 4,379 participants.

Assessments of depression

The nine-item Patient Health Questionnaire (PHQ-9) was used to evaluate depression [26]. The PHQ-9 consists of nine questions designed to assess the frequency of depressive symptoms experienced by participants, with responses recorded on a 4-point scale: 0 (not at all), 1 (a few days), 2 (more than half the days), and 3 (almost every day). The total score of the PHQ-9 is the sum of the 9 question scores, ranging from 0 to 27. Participants were considered to have clinically relevant depression if their total PHQ-9 scores exceeded 9 points [26].

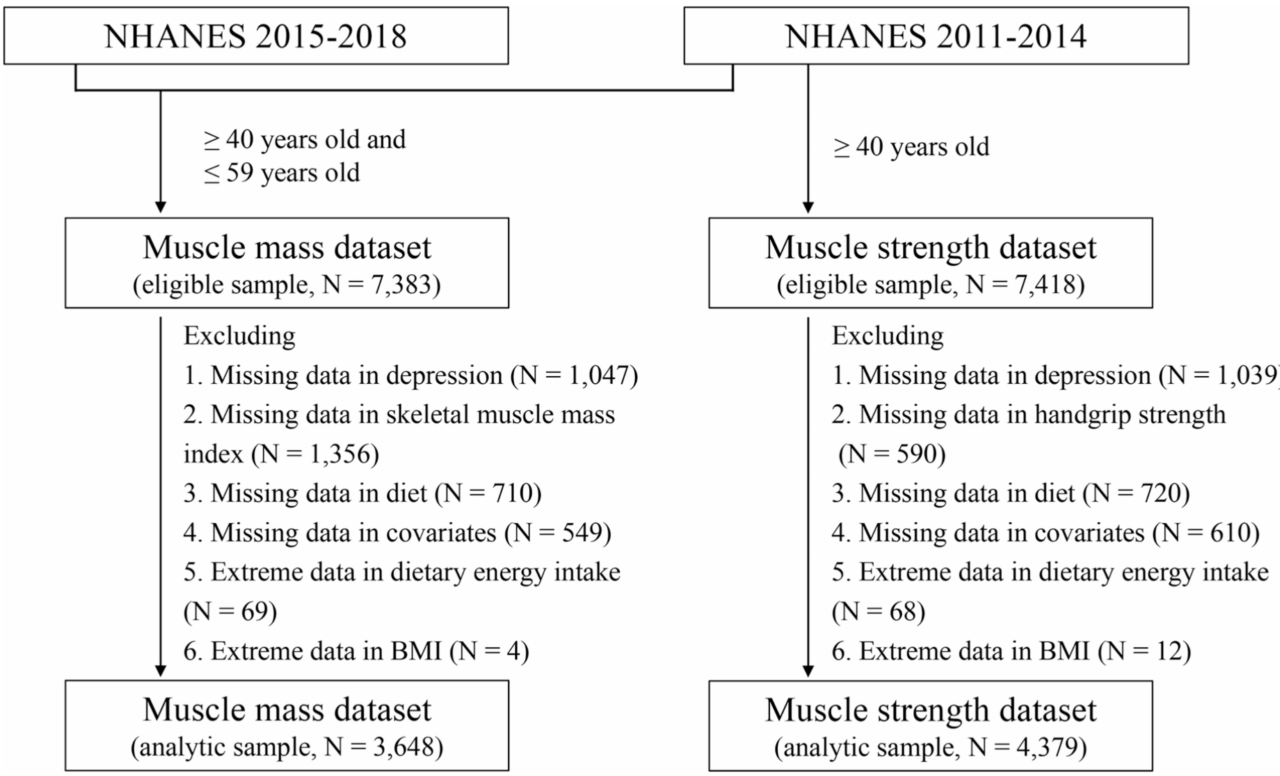

Fig. 1 The selection flows of participants in the present study

Measurements of muscle mass and muscle strength

The regional lean mass of participants aged between 40 and 59 was measured using dual-energy X-ray absorptiometry (DXA) scan. Appendicular lean mass (ASM) was calculated by summing arms lean mass and legs lean mass. Skeletal muscle mass index (SMI) [SMI (kg/m^2 = ASM (kg) / height squared (m^2)] was used as an indicator of muscle mass [3, 4].

A Takei digital grip strength dynamometer (Model T.K.K.5401) was used to assess Handgrip strength (HGS). Each hand of participants squeezed the dynamometer three times. The largest values from each hand were summed to calculate the combined handgrip strength [19].

Evaluation of dietary energy intake and healthy eating index 2015

Information on dietary intake was acquired via two 24-hour recalls [27]. The staffs recorded all foods and beverages consumed by participants the day prior to the interview [28, 29]. Dietary energy intake was calculated as the average of two days' energy intake from diet. Dietary quality was evaluated using the healthy eating index-2015 (HEI-2015), which represents the extent to which the food intake aligns with the 2015–2020 Dietary Guidelines for Americans [30, 31]. HEI-2015 is comprised of 13 components, and the total score of HEI-2015 ranges from 0 to 100 (the higher score indicates better dietary quality) [32]. HEI-2015 score in the present study was calculated using the SAS marco (Simple HEI Scoring Algorithm- Per Person), which was provided by the National cancer institute [32].

Covariates

Sociodemographic variables in this study included age categories (40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75–80, 80 and above), sex (men and women), race (Mexican American, other Hispanic, non-Hispanic White, non-Hispanic Black, and other race), education (below high school, high school, and college or above), marriage (not married, married or living with partner, and widowed or separated or divorced), and family monthly poverty level index (PIR) (≤ 1.3, 1.3–1.85, > 1.85), all of which were measured by questionnaire survey.

Smoking was classified as non-smoker, current smoker, and former smoker. Alcohol drinking was classified as drinker and non-drinker. Physical activity was evaluated using the Global Physical Activity Questionnaire [33]. The minutes of moderate to vigorous physical activity per week were multiplied by corresponding metabolic equivalent (MET) scores (8.0 MET/min for vigorous physical activity and 4.0 MET/min for moderate physical activity), and then each item was summed to calculate the total

MET consumed per week. Participants were defined as physically active if the total MET consumed ≥ 600 MET-minutes/week (equal to 75 min/week vigorous physical activity or 150 min/week moderate physical activity) [34]. Body mass index (BMI) was calculated by dividing weight by height squared.

Coronary heart disease, angina, heart attack, stroke, cancer, arthritis, and gout were defined if participants self-reported that they had physicians' diagnosis of corresponding diseases. Hypertension was defined if participants had elevated blood pressure (systolic blood pressure ≥ 130 mm Hg or diastolic blood pressure ≥ 80 mm Hg) or taken any antihypertensive drugs [35]. Diabetes was ascertained if participants had glycosylated hemoglobin ≥ 6.5%, or had physicians' diagnosis of diabetes, or taken medicine for diabetes [36, 37]. The number of comorbidities was calculated as the sum of all mentioned diseases above, and was categorized into three categories (0, 1, and ≥ 2 chronic diseases).

Statistical analyses

We compared the baseline characteristics between participants with and without depression. Weighted *t*-test and weighted chi-square test were used for comparison for continuous variables and categorical variables, respectively.

We conducted weighted multivariable linear regression models to explore the associations of depression with SMI and HGS, with adjustment for age categories, sex, race, marriage, education, PIR category, smoking, alcohol drinking, physical activity, BMI, dietary energy intake, HEI-2015, and comorbidity categories. In addition, to determine whether the associations of depression with SMI and HGS were modified by dietary energy intake or HEI-2015, we examined the interactions between depression and dietary energy intake and HEI-2015, and performed stratified analyses.

The mediation analyses were conducted to explore the extent to which the associations of depression with SMI and HGS were mediated by dietary energy intake and HEI-2015. We used the R package ('mediation', version 4.5.0) to perform the causal mediation analyses [38]. Direct effect, indirect effect, and total effect were estimated, and bootstrapping method (bootstrapped 10000 times) was used to test the significance of these effects.

The sensitivity analyses reran the interaction analyses—whether dietary energy intake and HEI-2015 modified the associations of depression with HGS— in participants aged between 40 and 59 (which is consistent with the muscle mass dataset), to determine whether the interaction effects were influenced by the difference in participants' ages. In addition, we investigated the associations of depression with SMI and HGS in participants aged betwen 20 and 39.

We used STATA version 15.0, SAS version 9.4 and R version 4.1.1 for all of the statistical analyses. The *P*-value < 0.05 (two-sided) was considered statistically significant.

Results

Baseline characteristics of participants

The baseline characteristics of participants with and without depression in muscle mass datasets were showed in Table 1. Compared to participants without depression, participants with depression were less likely to be male, married or living with partner, and highly educated, and more likely to be current smoker and physically inactive. Participants with depression had lower level of PIR, dietary energy intake, HEI-2015, and SMI, and had higher BMI and more comorbidities than those without.

The baseline characteristics of participants with and without depression in muscle strength datasets were exhibited in Table 2. Consistent with the results observed in muscle mass dataset, similar differences in sex, marriage, education, PIR categories, smoking, physical activity, BMI, dietary energy intake, HEI-2015, and comorbidity categories were observed between participants with and without depression. In addition, the difference in age categories, race, and HGS existed between participants with and without depression.

Associations of depression with muscle mass and muscle strength

The associations of depression with SMI and HGS were shown in Table 3. Depression was associated with decreased SMI (β, -0.10; 95% CI, -0.20, -0.00; *P* = 0.044) and decreased HGS (β, -3.08; 95% CI, -5.59, -0.58; *P* = 0.017).

Interaction effect analyses and stratified analyses

Interaction effect analyses showed that no significant interactions existed between depression and dietary energy intake for SMI (*P* for interaction = 0.828) and for HGS (*P* for interaction = 0.760) (Table 3). Significant interactions between depression and HEI-2015 were observed for SMI (*P* for interaction = 0.015), but not for HGS (*P* for interaction = 0.999) (Table 3).

The associations of depression with SMI and HGS in participants with different levels of dietary energy intake and HEI-2015 were showed in Fig. 2. Depression was inversely associated with SMI in participants whose HEI-2015 were lower than the median (β, -0.15; 95% CI, -0.28, -0.02; *P* = 0.024), but not in participants with HEI-2015 above the median. The stratified analyses also found that depression was associated with decreased SMI in participants whose dietary energy intake were lower than the median (β, -0.13; 95% CI, -0.26, 0.00; *P* = 0.048), and was associated with decreased HGS in participants whose

Table 1 Baseline characteristic of participants with and without depression (muscle mass dataset)

Variables	Without depression (n = 3,311)	Depression (n = 337)	P
Age categories			0.133
40–44	845 (22.9%)	68 (15.9%)	
45–49	857 (25.2%)	80 (24.4%)	
50–54	834 (24.6%)	88 (26.2%)	
55–59	775 (27.3%)	101 (33.5%)	
Sex (men)	1599 (49.2%)	109 (32.1%)	0.001
Race			0.211
Mexican American	434 (7.9%)	40 (8.4%)	
Other Hispanic	319 (5.8%)	51 (8.7%)	
Non-Hispanics White	1240 (67.0%)	154 (61.9%)	
Non-Hispanics Black	764 (10.5%)	55 (8.7%)	
Other Race	554 (8.8%)	37 (12.3%)	
Marriage			< 0.001
Not married	370 (8.7%)	61 (15.6%)	
Married or living with partner	2279 (71.3%)	147 (46.0%)	
Widowed, separated, or divorced	662 (20.0%)	129 (38.4%)	
Education			0.003
Below high school	531 (10.4%)	93 (18.8%)	
High school	715 (22.4%)	86 (29.3%)	
College or above	2065 (67.3%)	158 (52.0%)	
Family monthly poverty level index category			< 0.001
≤ 1.3	915 (18.1%)	182 (43.8%)	
1.3–1.85	440 (10.5%)	45 (11.7%)	
> 1.85	1956 (71.4%)	110 (44.5%)	
Smoking			< 0.001
Never	1929 (56.7%)	114 (29.4%)	
Current	674 (19.1%)	144 (50.2%)	
Former	708 (24.2%)	79 (20.4%)	
Alcohol drinking (yes)	2428 (79.4%)	251 (80.5%)	0.679
Physical activity			0.003
Active	2135 (68.5%)	178 (54.4%)	
Inactive	1176 (31.5%)	159 (45.6%)	
Body mass index (kg/m^2)	29.1 (0.19)	30.6 (0.47)	0.005
Dietary energy intake (kcal)	2101.1 (21.0)	1828.1 (44.5)	< 0.001
Healthy eating index-2015	55.0 (0.44)	49.9 (1.21)	< 0.001
Skeletal muscle mass index (kg/m^2)	7.9 (0.05)	7.6 (0.11)	0.004
Comorbidity categories			< 0.001
0	1061 (33.6%)	64 (17.6%)	
1–2	1290 (39.3%)	104 (35.1%)	
> 2	960 (27.0%)	169 (47.3%)	

Note: Weighted means (standard errors) and frequency (weighted percentages) were presented for continuous variables and categorical variables, respectively

dietary energy intake above the median (β, -2.65; 95% CI, -5.24, -0.06; $P = 0.045$).

Mediation analyses

The mediating effects of dietary energy intake and HEI-2015 on the associations of depression with SMI and HGS were presented in Table 4. Dietary energy intake significantly mediated the associations of depression with SMI and HGS, and the mediation proportions were 25.2% and 7.8%, respectively. There was no significant mediating effect of HEI-2015 on the associations of depression with SMI and HGS.

Sensitivity analyses

The sensitivity analyses found that depression was associated with decreased HGS in participants aged between 40 and 59, but the *P* value was nearly significant ($P = 0.065$) (Supplementary table S1). No significant interaction was observed between depression and dietary energy intake (*P* for interaction = 0.823), as well as between depression

Table 2 Baseline characteristic of participants with and without depression (muscle strength dataset)

	Without depression (n = 3,987)	Depression (n = 392)	P
Age categories			0.019
40–44	522 (13.1%)	39 (7.9%)	
45–49	527 (14.1%)	53 (17.8%)	
50–54	532 (16.2%)	62 (16.4%)	
55–59	471 (15.3%)	63 (22.1%)	
60–64	578 (13.1%)	74 (16.6%)	
65–69	429 (9.9%)	43 (9.7%)	
70–74	380 (7.7%)	26 (4.3%)	
75–79	231 (4.7%)	12 (1.7%)	
80-	317 (5.9%)	20 (3.5%)	
Sex (men)	1,963 (48.1%)	131 (34.5%)	0.002
Race			0.028
Mexican American	364 (5.1%)	42 (6.6%)	
Other Hispanic	343 (4.2%)	53 (7.8%)	
Non-Hispanics White	1,863 (74.5%)	178 (65.7%)	
Non-Hispanics Black	957 (10.0%)	90 (11.8%)	
Other Race	460 (6.3%)	29 (8.0%)	
Marriage			< 0.001
Not married	356 (6.9%)	51 (12.8%)	
Married or living with partner	2,533 (69.1%)	177 (49.2%)	
Widowed, separated, or divorced	1,098 (24.0%)	164 (38.1%)	
Education			< 0.001
Below high school	752 (12.1%)	133 (24.7%)	
High school	885 (21.5%)	88 (25.5%)	
College or above	2,350 (66.4%)	171 (49.8%)	
Family monthly poverty level index category			< 0.001
≤ 1.3	1,091 (17.6%)	210 (42.3%)	
1.3–1.85	535 (10.9%)	57 (13.3%)	
> 1.85	2,361 (71.5%)	125 (44.4%)	
Smoking			< 0.001
Never	2,155 (54.6%)	155 (35.4%)	
Current	642 (15.5%)	119 (33.8%)	
Former	1,190 (29.8%)	118 (30.8%)	
Alcohol drinking (yes)	2,912 (79.0%)	296 (82.8%)	0.205
Physical activity			0.002
Active	2,294 (60.9%)	159 (43.9%)	
Inactive	1,693 (39.1%)	233 (56.1%)	
Body mass index (kg/m^2)	29.3 (0.22)	31.7 (0.46)	< 0.001
Dietary energy intake (kcal)	2028.0 (19.5)	1833.2 (46.4)	0.001
Healthy eating index-2015	56.7 (0.41)	51.9 (0.90)	< 0.001
Handgrip strength (kg)	69.9 (0.63)	62.0 (1.36)	< 0.001
Comorbidity categories			< 0.001
0	817 (23.2%)	49 (11.8%)	
1–2	1321 (34.2%)	87 (27.7%)	
> 2	1849 (42.7%)	256 (60.5%)	

Note: Weighted means (standard errors) and frequency (weighted percentages) were presented for continuous variables and categorical variables, respectively

Table 3 Associations of depression with skeletal muscle mass index and handgrip strength

	Skeletal muscle mass index (*n* = 3,648)			**Handgrip strength (*n* = 4,379)**		
	β (95% CI)	*P*	*P* for interaction	β (95% CI)	*P*	*P* for interaction
Depression						
No	Referent			Referent		
Yes	-0.10 (-0.20, -0.00)	0.044		-3.08 (-5.59, -0.58)	0.017	
Dietary energy intake *	0.07 (0.04, 0.10)	< 0.001	0.828	1.14 (0.54, 1.73)	< 0.001	0.760
HEI-2015 *	0.04 (0.00, 0.08)	0.048	0.015	-0.07 (-0.66, 0.52)	0.811	0.999

Adjusted for age categories, sex, race, marriage, education, family monthly poverty level index category, smoking, alcohol drinking, physical activity, body mass index, and comorbidity categories

* Dietary energy intake and HEI-2015 underwent standardization before being incorporated into the regression models

β, beta coefficient; CI, confidence interval; HEI-2015, healthy eating index-2015

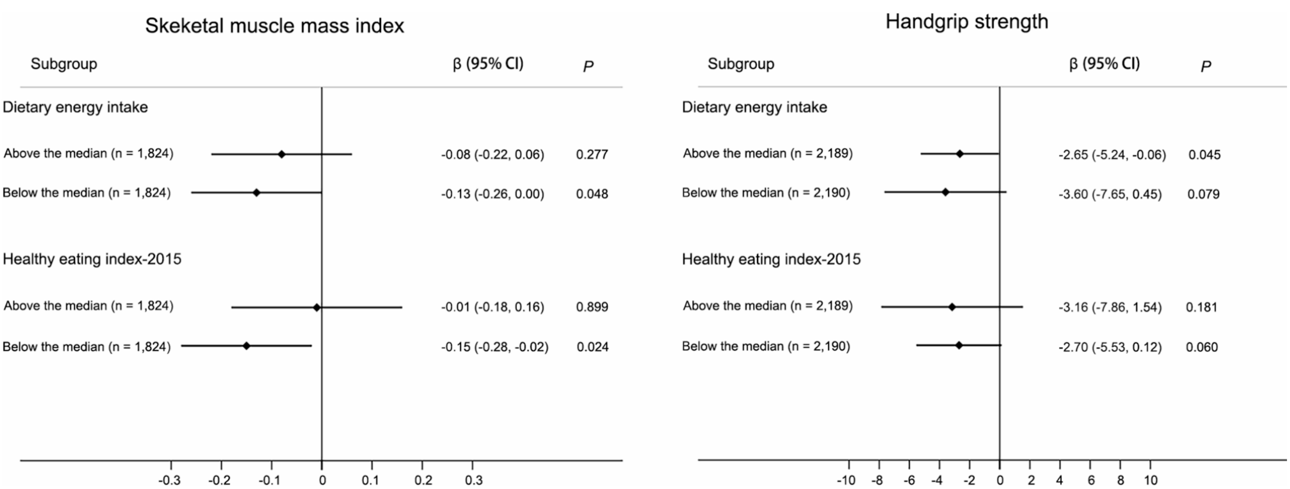

Fig. 2 Associations of depression with skeletal muscle mass index and handgrip strength in participants with different levels of dietary energy intake and healthy eating index-2015. Adjusted for age categories, sex, race, marriage, education, family monthly poverty level index category, smoking, alcohol drinking, physical activity, body mass index, dietary energy intake/ healthy eating index-2015, and comorbidity categories. β, beta coefficient; CI, confidence interval

Table 4 The mediation effects of dietary energy intake and healthy eating index-2015 on the associations of depression with skeletal muscle mass index and handgrip strength

	Indirect effect		**Direct effect**		**Total effect**		**Proportion Mediated (%)**
Mediators and outcomes	**Estimate (95% CI)**	***P***	**Estimate (95% CI)**	***P***	**Estimate (95% CI)**	***P***	
Dietary energy intake							
Skeletal muscle mass index (*n* = 3,648)	-0.028 (-0.036, -0.003)	0.011	-0.083 (-0.228, 0.028)	0.117	-0.110 (-0.247, 0.012)	0.076	25.2
Handgrip strength (*n* = 4,379)	-0.454 (-0.553, -0.002)	0.048	-5.374 (-5.983 -0.617)	0.012	-5.828 (-6.407, -0.779)	0.008	7.8
Healthy eating index-2015							
Skeletal muscle mass index (*n* = 3,648)	-0.008 (-0.023, 0.002)	0.138	-0.083 (-0.228, 0.028)	0.117	-0.091 (-0.239, 0.022)	0.099	NA
Handgrip strength (*n* = 4,379)	0.127 (-0.115, 0.129)	0.907	-5.374 (-5.983, -0.617)	0.012	-5.247 (-5.995, -0.619)	0.012	NA

Adjusted for age categories, sex, race, marriage, education, family monthly poverty level index category, smoking, alcohol drinking, physical activity, body mass index, dietary energy intake/ healthy eating index-2015, and comorbidity categories

CI, confidence interval

and HEI-2015 (P for interaction = 0.514) for HGS. The stratified analyses did not observe significant associations between depression and HGS in any subgroups. No significant association of depression with SMI or HGS was observed in participants aged between 20 and 39 (Supplementary table S2).

Discussion

In this nationally representative data of the US civilian, we found that depression was inversely associated with SMI and HGS, and HEI-2015 modified the associations between depression and SMI. Depression was associated with decreased SMI only in participants whose HEI-2015 was lower than the median. In addition, we found that the associations of depression with SMI and HGS were mediated by dietary energy intake.

Depression, low muscle mass, and low muscle strength were common disorders among the U.S. civilian population [39, 40]. Therefore, exploring the associations of depression with muscle mass and muscle strength, and investigating the role of diet in these associations are quite meaningful. Clarifying the inverse associations of depression with muscle mass and muscle strength might alter individuals with depression to monitor their muscle condition. Elucidating the moderating effect and mediating effect of dietary energy intake and dietary quality on the associations of depression with muscle mass and muscle strength could provide clues for raising effective strategies in improving muscle condition for people with depression. Several health policies should be considered to address the dual burden of depression and muscle loss. Regular screening for depression should be conducted by healthcare professionals in middle-aged and older individuals to facilitate early diagnosis and prevention of depression-related adverse events. Furthermore, direct interventions targeting both depression and muscle health, including regular screening for muscle health, community programs addressing both conditions, and the enhancement of dietary quality and energy intake, should be implemented by primary healthcare providers to preserve muscle health in individuals with depression.

Previous studies reported inconsistent associations of depression with muscle mass and muscle strength. Some studies found that an inverse association between depression and both muscle mass and muscle strength [18, 19], while other studies have found no association between depression and either muscle mass and muscle strength [20, 21]. Our findings supported the notion that depression was inversely associated with muscle mass and muscle strength. Biological and behavioral changes associated with depression, such as dysfunction in hypothalamic–pituitary–adrenal axis (HPA), physical inactivity and dietary changes might contribute to these associations [41–45].

The present study observed that the inverse associations between depression and muscle mass were modified by HEI-2015, and these associations only existed in participants with lower level of HEI-2015. High dietary quality was a protective factor of low muscle mass [46–48]. Studies found that increased dietary quality was inversely associated with low muscle mass among older people aged 75 and above [46], and women with higher dietary quality had less loss of muscle mass over 3-year or 5-year follow-up [47, 48]. Therefore, the impact of depression on muscle mass might be mitigated in participants who maintain a high-quality diet.

The reason why the interaction effect between depression and HEI-2015 was observed for muscle mass but not for muscle strength is complicated. We firstly thought this inconsistency might be caused by the difference in participants' ages between the muscle mass dataset and muscle strength dataset. However, the sensitivity analyses−−reanalyzing the interaction effects between depression and HEI-2015 for muscle strength specifically in participants aged between 40 and 59 years, yielded comparable results to those obtained in the main analyses. We then considered this inconsistency might be explained by the different associations of HEI-2015 with muscle mass and muscle strength in our study−− HEI-2015 was associated with SMI but not HGS. To date, the associations between healthy eating index and muscle strength were debated. Some studies proposed the view that adherence to healthy eating index might prompt muscle strength [49, 50], while other studies have reached different conclusions [51, 52]. Further studies with large sample size are needed to validate our results and explore the underlying mechanism.

Furthermore, the inverse association between depression and HGS was observed in participants with dietary energy intake above the median, in contrast to the association observed for muscle mass. The difference in participants' ages between the muscle mass dataset and muscle strength datasets might explain this inconsistency. Sensitivity analyses revealed that when the analyses were restricted to participants aged 40 to 59, depression was not associated with handgrip strength in participants whose dietary energy intake was above the median, consistent with the result observed for muscle mass. Moreover, the limited sample size within each subgroup may further explain this inconsistency. Although not statistically significant, in the dataset of participants aged 40 years or older, the P-value for the inverse association between depression and handgrip strength was 0.079 in participants with dietary energy intake below the median, which was near the threshold of significance. When the analyses were restricted to participants aged 40 to 59 years, similar results were observed in those with dietary energy intake below the median (P = 0.070).

This study also found that dietary energy intake mediated partly the associations of depression with muscle mass and muscle strength. Previous studies showed that participants with depression had less total calorie intake [42], and the decrease in energy intake might impair muscle health by weakening the synthesis of protein and reducing the size of myofibrils [53, 54]. Population-based studies have also observed positive associations between insufficient energy intake and risk of low muscle mass, as well as low muscle strength [55–57]. Our findings suggested that the reduced energy intake might be the pathways how depression established connections with muscle mass and muscle strength.

We also observed that participants with depression were less likely to be married or living with a partner, and more likely to be current smokers. These findings were consistent with previous study [58, 59]. Coping resources offered by marriage or partnership, such as intimacy, social networks, and enhanced self-esteem, could mitigate the impact of genetic predisposition and environmental stressors on depression [58]. Smoking may increase the risk of depression by causing psychological and emotional damage [59, 60].

Several advantages existed in the present study. To the best of our knowledge, our study firstly found that HEI-2015 could modify the associations between depression and muscle mass, and dietary energy intake mediated the associations of depression with muscle mass and muscle strength. Besides, the possible role of diet in the associations of depression with muscle mass and muscle strength was clarified from a macroscopic view— focusing on the dietary energy intake and dietary quality instead of certain food categories or specific nutrition intake. Furthermore, this study was conducted in a nationally representative sample of US adults, which provided a certain degree of generalizability of our findings. Finally, muscle mass was assessed by DXA scan, which was widely regarded as a reliable and accurate measurement.

This study also had some limitations. First, since this study was a cross-sectional study, we were unable to elucidate the causal relationships between depression and muscle mass and muscle strength. Second, the data on muscle mass in participants aged 60 and above were unavailable, meaning that our study's findings about muscle mass applied only to middle-aged individuals. Further studies with longitudinal design and performed in middle-aged and elderly adults are needed. Third, because dietary intake in NHANES was evaluated by two non-consecutive 24-hour dietary recalls and depression was measured by questionnaire interview, reporting bias and recall bias were inevitable.

Conclusion

In conclusion, the present study found that depression was associated with decreased muscle mass in middle-aged individuals and reduced muscle strength in both middle-aged and older individuals. The inverse associations between depression and muscle mass were modified by HEI-2015, and these associations only existed in participants with low HEI-2015. In addition, the reduction in dietary energy intake might link depression to decreased muscle mass and muscle strength. Healthcare professionals should monitor the change of muscle mass and muscle strength in middle-aged and older individuals with depression, and recognize the role of dietary energy intake and dietary quality in maintaining muscle health.

Abbreviations

ASM	Appendicular lean mass
BMI	Body mass index
DXA	Dual-energy X-ray absorptiometry
HEI-2015	Healthy eating index-2015
HGS	Handgrip strength
MET	Metabolic equivalent
NHANES	National Health and Nutrition Examination Survey
PHQ-9	Nine-item Patient Health Questionnaire
SMI	Skeletal muscle mass index

Supplementary Information

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Supplementary Material 1

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Author contributions

DG, XBW, XH, and SH designed the study. DG and XBW analyzed the data. DG and XBW wrote the manuscript. DG, XBW, YJZ, YG, XH, and SH provided comments and revised the manuscript. XH and SH supervised the study. All authors read and approved the final version of the manuscript.

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Data availability

The survey data are publicly available on the internet for data users and researchers throughout the world (https://www.cdc.gov/nchs/nhanes/index.htm.).

Declarations

Ethics approval and consent to participate

The NHANES procedures and protocols were approved by the National Center for Health Statistics Research Ethics Review Board. All participants provided the written informed consent before involving in this survey.

Consent for publication
Not applicable.

Competing intrests
The authors declared no conflict of interest.

Author details
[1]Jiangxi Medicine Academy of Nutrition and Health Management, The First Affiliated Hospital, Jiangxi Medical College, Nanchang University, Nanchang 330006, Jiangxi, China
[2]Center for Molecular Pathology, Department of Pathophysiology, Gannan Medical University, Ganzhou, Jiangxi, China
[3]Department of Geriatrics, Hangzhou First People's Hospital, Hangzhou 310006, Zhejiang, China
[4]Zhejiang Key Laboratory of Traditional Chinese Medicine for the Prevention and Treatment of Senile Chronic Diseases, Hangzhou, Zhejiang, China

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