

RESEARCH

Open Access



Muscle quality index and cardiovascular disease among US population-findings from NHANES 2011–2014

Yanlin Chen¹, Weidong Lin¹, Lu Fu¹, Huiyi Liu¹, Shuyu Jin², Xingdong Ye¹, Sijia Pu³ and Yumei Xue^{1,2,3*}

Abstract

Background and objective Cardiovascular disease (CVD) is the leading cause of morbidity and mortality in the United States. However, current evidence on the association between muscle quality and CVD is limited. This study investigates the potential association between the muscle quality index (MQI) and the prevalence of CVD and CVD-related mortality.

Methods Participants were selected from the National Health and Nutrition Examination Survey (NHANES) 2011–2014. Data on mortality and causes of death were obtained from the National Death Index (NDI) records through December 31, 2019. Statistical analysis used in this study, including weighted multivariable linear and logistic regression, cox regression and Kaplan-Meier (K-M) analysis, to estimate the association between MQI and all-cause mortality as well as CVD mortality. In addition, subgroup analysis was used to estimate the association between MQI and CVD subtypes, such as heart attack, coronary heart disease, angina, congestive heart failure, and stroke.

Results A total of 5,053 participants were included in the final analysis. Weighted multivariable linear regression models revealed that a lower MQI total level was independently associated with an increased risk of CVD development in model 3, with t value = -3.48, 95%CI: (-0.24, -0.06), $P=0.002$. During 5,053 person-years of 6.92 years of follow-up, there were 29 deaths from CVD. Still, the association between MQI total and CVD mortality, as well as all-cause mortality did not reach statistical significance in the fully adjusted model (HR=0.58, 95% CI: 0.21–1.62, $P=0.30$; HR=0.91, 95% CI: 0.65, 1.28, $P=0.59$, respectively). Subgroup analysis confirmed that MQI total was negatively associated with congestive heart failure (OR=0.35, 95% CI=0.18, 0.68, $P=0.01$).

Conclusion This study highlights the potential of MQI as a measure of muscle quality, its negative correlation with congestive heart failure (CHF). However, MQI was not very useful for predicting the health outcomes such as CVD and mortality. Therefore, more attention should be paid to the early recognition of muscle weakness progression in CHF. Further studies are needed to explore more effective indicator to evaluate the association between muscle quality and health outcomes.

Keywords Muscle quality index, Cardiovascular Disease, Resistance exercise, National Health and Nutrition Examination Survey

*Correspondence:
Yumei Xue
xymgdci@163.com

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



© The Author(s) 2023. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

Introduction

Cardiovascular disease (CVD) is the leading cause of morbidity and mortality in the United States [1]. In 2017, CVD accounted for approximately 859,125 deaths in the United States [2]. Additionally, the total cost of CVD in the United States was about \$351.2 billion between 2014–2015 [2]. Although traditional risk factors, such as hypertension, obesity, hyperglycemia and smoking, have been well-qualified, other factors that are associated with CVD have been gradually recognized, including muscle mass, strength and quality [3].

Skeletal muscle consists of 40–50% of total body weight [4]. With increasing age, muscle mass declines by 0.37% and 0.47% per year in women and men, respectively [5]. Interestingly, the loss of muscle mass and strength does not mean a decrease in body weight, as the lost muscle may be replaced by nonfunctional fat, such as visceral fat, leading to muscle weakness [6]. Body muscle is metabolically active, which is identified as anti-hyperglycemia and anti-inflammation [7]. Recent clinical studies reported that the reduced muscle mass could be much higher in CVD patients compared with healthy population [8, 9]. Hajahmadi et al. found that 47.3% of patients with dilated cardiomyopathy, with an average age of 37 years, exhibited muscle wasting [10]. Similarly, patients who received transcatheter aortic valve implantation (TAVI) were followed for 12 months, and it was found that those with the lowest psoas muscle mass showed the highest new-onset atrial fibrillation and mortality [11]. Therefore, the muscle condition may serve as a novel predictor for prognosticating and evaluating the risk of CVD. Muscle mass can be measured by magnetic resonance imaging or dual-energy X-ray absorptiometry (DXA) scans. Hand-grip strength (HGS) is a direct measure of arm strength and an indirect evaluation of overall muscular strength [3] (HGS can be well correlated with the whole muscle strength [12]). However, muscle wasting does not synchronize with the loss of muscle strength, as the loss of muscle strength is faster than muscle wasting [13]. The muscle quality index (MQI) is used to describe the muscle strength per unit of muscle mass and has been recognized as an indicator to access the body muscle [14, 15]. Several methodologic approaches have been employed to calculate MQI values, which have been discussed in previous articles [16–19].

Since both muscle mass and muscle strength have been shown to be relative to disability risk and CVD mortality, large and representative data are needed to identify these correlations. We acknowledge there are various methods to evaluate body muscle quality; thus, in this study, we adopted Lopes, L. et al. to introduce the MQI method to explore the relationship between MQI and health outcomes (CVD and mortality) [20]. We hypothesized that MQI plays a role in cardiovascular health.

Methods

Data collection

Data used in this cross-sectional and longitudinal study was from the National Health and Nutrition Examination Survey (NHANES). NHANES is a large-scale, ongoing and representative healthy survey of the U.S. civilians aged over 2 months [21]. NHANES has been approved by the National Center for Health Statistics (NCHS) Ethics Review Board (ERB) and participants have written consent. The detailed protocol of data collection is described at <http://www.cdc.gov/nchs/nhanes>.

Due to the MQI test being only available in the 2011–2014 period, thus, the dataset was collected from these 2 cycles of NHANES, 2011–2012 and 2013–2014. And we excluded participants below 20 and over 60, as the body composition data was unavailable. In addition, the study excluded the participants who lacked CVD data and incomplete covariates (Fig. 1).

Exposure measurement methods

According to Lopes, L. et al. introduced the method to calculate MQI [22]. MQI_{Arm} (kg/kg) was the ratio between dominant HGS (measured by a Takei dynamometer) and dominant arm appendicular skeletal muscle mass (arm ASM accessed by DXA) [22]. In the same way, MQI_{App} (kg/kg) was the ratio of dominant HGS/ASM (ASM has been defined by the sum of four limbs of lean soft tissue); and the MQI_{Total} was the ratio of HGS sum/ASM (HGS sum was the sum of the dominant hand and the non-dominant hand) [22]. The continuous variable of MQI_{Total} has been transferred into categorical variable based on what Lopes, L. et al. reported; the MQI_{Total} cut-off values were established for both different ethnicities and sexes, which were normal, low and extremely low MQI_{Total} groups [22]. The rationale for use of the MQI cut-offs values was: previous studies showed variations in HGS and body composition across different sexes and racial [22–24], suggesting a sex- and population-specific MQI cut-off values should be established. Therefore, low MQI_{Total} were defined as 1 standard deviation (SD) below the mean of young adult reference, and extremely low MQI_{Total} defined as 2 SD below the young adult reference mean (the young adult group including male and female, age from 20 to 39 years old, and with normal BMI range), more details were shown in Supplementary Table 1.

Outcome variable selections

The outcomes selection in this study were CVDs and mortality. Reported or self-admitted physician diagnoses obtained CVD. Self-admitted CVD was assessed by asking the following questions: “Has a doctor or other health professional ever told you that you have a heart attack/coronary heart disease/ angina / congestive heart failure/ stroke?” The answer could be “Yes/No/didn’t know”;

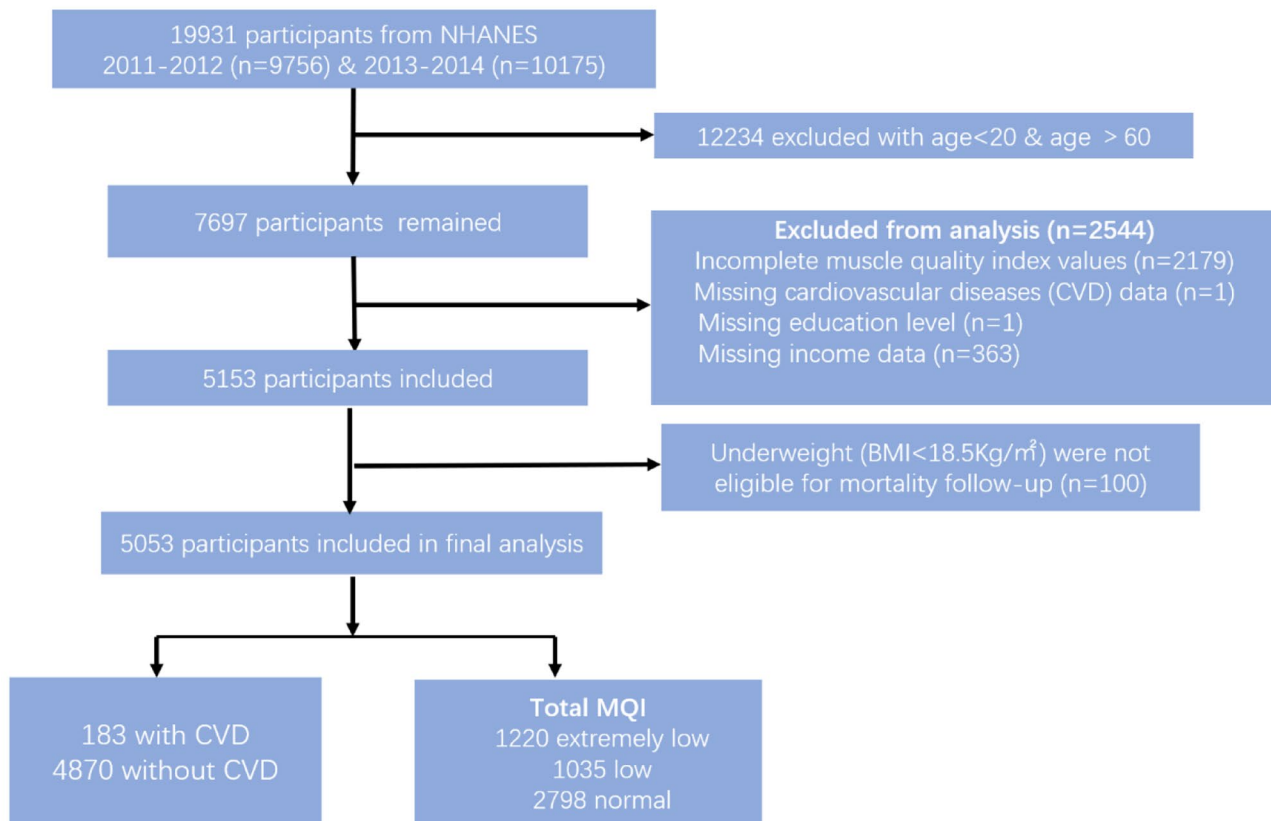


Fig. 1 The flowchart of study sample selection from NHANES 2011–2012 and 2013–2014

and “Yes” was considered as a CVD patient; the “didn’t know” participants would be excluded. Mortality due to all-cause and CVD was determined by connecting to the National Death Index (NDI) until December 31, 2019. The ICD-10 (codes I00–I09, I11, I13, I20–I51, or I60–I69) was employed to identify CVD mortality. The “2019 Public-Use Linked Mortality Files” were available on the NCHS website (<https://www.cdc.gov/nchs/data-linkage/mortality-public.htm>). We started from MQI-related data collection and ended on or before December 31, 2019. In addition, participants who did not have a matching death record were considered to be alive throughout the entire follow-up period.

Covariates extraction

Covariates that could potentially affect the relationship between MQI and the risk of CVD/ CVD mortality were collected through interviews and medical examinations. The covariates have been divided into continuous variables and categorical variables. Continuous variable was the age; categorical variables including ethnicity (Non-Hispanic White, Non-Hispanic Black, Mexican American and other), sex (female, male), hypertension (no/yes), diabetes (no/yes), smoking status (no/yes), alcohol use (no/yes), educational level (less than 9th grade, 9–11th

grade, high school grad/GED or equivalent, some college or AA degree, college graduate or above), body mass index < 18.5 was excluded in the analysis due to underweight (BMI, 18.6–25, 25–30, ≥ 30), family poverty-income ratio (PIR, low income < 1, 1 \leq middle income < 3, high income ≥ 3).

Evidence showed that the moderate to vigorous aerobic physical activity (MVPA) and sedentary behavior were associated with CVD and mortality [25, 26], which as potential confounders in this study. Participants completed the Global Physical Activity Questionnaire (GPAQ), developed by the World Health Organization (WHO) [27], gathers information on sedentary behavior and the amount of time individuals spend per week engaging in physical activity across three domains: leisure, work, and travel. It assesses both moderate activities like brisk walking or cycling and vigorous activities like running or football. This self-report questionnaire consists of 16 questions. According to the Physical Activity Guidelines from US 2018 [28], MVPA was classified into categorical variables: low (< 150 min/week), moderate (150–300 min/week), and high (> 300 min/week) [29]. In addition, daily sitting time was extracted by asking participants, “On a typical day, how much time usually spend sitting at school, at home, getting to and from

places, or with friends including time spent sitting at a desk, traveling in a car or bus, reading, playing cards, watching television, or using a computer, but did not include time spent sleeping?" Based on previous studies [30, 31], the daily sitting time was converted to hours/day (h/d), and divided into 4 groups (0 to <4, 4 to <6, 6 to 8, and ≥ 8).

Statistical analysis

Statistical analyses were performed with R software (version 4.3.0). Proper weighting procedures were applied with the guidance of NHANES guidelines to derive accurate estimates that could represent the U.S. population, as the complex survey design. The weights calculation for 2011–2014 was created by taking one-half for each participant who was sampled in 2011–2012 and one-half for each participant who was sampled in 2013–2014 [$1/2 * WTMEC2YR_{(2011-2012)} + 1/2 * WTMEC2YR_{(2013-2014)}$], $WTMEC2YR$ is weight variable for 2011–2014]. Continuous variables were presented as means and standard error (SE), and categorical variables were presented as frequency plus percentage. To compare different variables, t-tests and Mann-Whitney U tests were employed for continuous variables, the chi-square test was used for categorical variables. Weighted linear regression analysis was performed to explore the association between MQI_{Total} and CVD. Meanwhile, weighted logistic regression was conducted to further validate the relationship between MQI_{Total} and CVD, estimating odds ratios (OR) with corresponding 95% confidence intervals (CI). Four analyzes models have been established to remove covariates affect, model 1 without covariate adjustment; Model 2 adjusted with physical activity; Model 3 adjusted with sex, age, ethnicity, and physical activity; Model 4 was further adjusted with hypertension, diabetes, smoking status, alcohol use, educational level, poverty-income ratio (PIR), and body mass index (BMI), and daily sitting time. All analyzed data were used for the cross-sectional analyses in the present study. Furthermore, participants were followed-up, and the association between MQI_{Total} and mortality was evaluated using cox regression and Kaplan-Meier (K-M) analysis with time-to-events as the time variable, estimating the hazard ratios (HR) and 95% CI. Subgroup analyses were performed to estimate the association between MQI_{total} and CVD subtypes (angina, stroke, heart attack, coronary heart disease, congestive heart failure). All statistical tests were two-sided, and a significance level of $P < 0.05$ was considered statistically significant.

Results

This cross-sectional and longitudinal study enrolled 19,931 participants in the NHANES from 2011 to 2014. Among them, 12,234 participants were excluded with

age < 20 and age > 60 as the body composition data was not available. In addition, 2,179 were excluded due to incomplete MQI values. After missing covariates were eliminated from the study, 5,053 participants were enrolled in the final analysis (shown in Fig. 1). The 5,053 NHANES participants with valid MQI values represented approximately 11.93 million noninstitutionalized residents in the USA. Population characteristics of the study are shown in Table 1. Among the participants, 183 had CVD and 4,870 did not. The prevalence of CVD in females and males was 2.83% (N=86) and 3.45% (N=97), respectively. The average age of non-CVD participants was 39.12 ± 0.41 , and CVD was 48.47 ± 0.78 . Compared to participants without CVD, those with CVD tended to be older, have lower education levels, engage in unhealthy habits (smoking and drinking), and have a higher prevalence of risk factors (hypertension, diabetes, and obesity). Most importantly, participants diagnosed with CVD had lower muscle mass and muscle strength, as indicated by lower MQI values (MQIc.arm, MQIc.app and MQIc.total), compared to the population without CVD.

As shown in Table 2, we investigated the association between MQI_{total} values and the outcome of CVD by using linear regression. In Model 1 (no covariate was adjusted), relative to non-CVD participants, CVD participants had significantly lower MQI_{total} values compared to non-CVD participants (mean difference, 0.28 kg/kg; $P < 0.0001$); in Model 2 (physical activity were adjusted), CVD participants had lower MQI_{total} values compared with non-CVD (mean difference, 0.21 kg/kg; $P < 0.0001$); in Model 3 (sex, age, ethnicity, and physical activity were adjusted), CVD participants still exhibited lower MQI_{total} values (mean difference, 0.15 kg/kg; $P = 0.002$); After further adjustment in Model 4 (sex, age, ethnicity, physical activity, hypertension, diabetes, smoking status, alcohol use, educational level, PIR, BMI, and daily sitting time were further adjusted), MQI_{total} values was not independently associated with CVD (mean difference, 0.09 kg/kg; $P = 0.09$). Logistic regression (Table 3) was performed to validate the MQI_{total} level was negatively associated with the odds ratio (OR) of CVD [Model 1: OR (95% CI) = 0.47 (0.35–0.63), $P < 0.0001$; Model 2: OR (95% CI) = 0.55 (0.42–0.72), $P < 0.001$; Model 3: OR (95% CI) = 0.65 (0.50–0.84), $P = 0.002$]. However, after fully adjustment in Model 4, the MQI_{total} values was not independently associated with CVD [Model 4: OR (95% CI) = 0.79 (0.49–1.29), $P = 0.31$].

During 5,053 person-years of follow-up (median follow-up, 6.96 years) from the NHANES 2011–2014, a total of 127 deaths were documented, with 29 deaths attributed to CVD. First, the multivariable adjustment was applied to analyze the association between MQI_{total} and all-cause mortality. The results revealed a negative association between MQI_{total} and all-cause mortality [Model

Table 1 The general characteristics of the population in NHANES 2011–2014, statistical analysis was presented with Mean \pm SE and Percentage (frequency). CVD, cardiovascular disease. BMI, body mass index. MQIc.arm, categorical value of muscle quality index for arms. MQIc.app, categorical value of muscle quality index for four limbs. MQIc.total, categorical value of whole-body muscle quality index

Variable	Total (5053)	Non-CVD (4870)	CVD (183)	P value
Age	39.41 \pm 0.40	39.12 \pm 0.41	48.47 \pm 0.78	< 0.0001
Sex				0.25
Female	2464(48.76)	2378(97.17)	86(2.83)	
Male	2589(51.24)	2492(96.55)	97(3.45)	
Ethnicity				0.31
Non-Hispanic White	2034(40.25)	1955(96.87)	79(3.13)	
Non-Hispanic Black	1097(21.71)	1047(95.86)	50(4.14)	
Mexican American	612(12.11)	590(97.12)	22(2.88)	
Other	1310(25.93)	1278(97.32)	32(2.68)	
Education Level				0.002
Less than 9th grade	229(4.53)	219(96.60)	10(3.40)	
9-11th grade	610(12.07)	571(94.19)	39(5.81)	
High school graduate/GED or equivalent	1074(21.25)	1025(95.52)	49(4.48)	
Some college or AA degree	1703(33.7)	1646(96.85)	57(3.15)	
College graduate or above	1437(28.44)	1409(98.55)	28(1.45)	
Smoke	1204(23.84)	1128(93.92)	76(6.08)	< 0.0001
Poverty Level				< 0.001
low income	1736(34.36)	1653(95.22)	83(4.78)	
middle income	1647(32.59)	1580(96.16)	67(3.84)	
high income	1670(33.05)	1637(98.34)	33(1.66)	
Alcohol User	3687(76.94)	3573(97.39)	114(2.61)	0.01
Hypertension	1431(28.32)	1306(92.54)	125(7.46)	< 0.0001
Diabetes	680(13.46)	618(90.98)	62(9.02)	< 0.0001
BMI (kg/m²)				0.001
18.5–25	1617(32)	1581(98.35)	36(1.65)	
25–30	1625(32.16)	1570(97.01)	55(2.99)	
\geq 30	1811(35.84)	1719(95.37)	92(4.63)	
MQIc.arm				< 0.0001
extremely low	734(14.53)	680(93.91)	54(6.09)	
low	1059(20.96)	1010(96.21)	49(3.79)	
normal	3260(64.52)	3180(97.87)	80(2.13)	
MQIc.app				< 0.0001
extremely low	751(14.86)	692(93.57)	59(6.43)	
low	1118(22.13)	1078(97.02)	40(2.98)	
normal	3184(63.01)	3100(97.72)	84(2.28)	
MQIc.total				< 0.0001
extremely low	1220(24.14)	1139(94.60)	81(5.40)	
low	1035(20.48)	994(96.65)	41(3.35)	
normal	2798(55.37)	2737(97.99)	61(2.01)	
Daily sitting time (hour)				0.07
<4	1058(20.94)	1017(96.65)	41(3.35)	
4 to <6	1119(22.15)	1090(97.85)	29(2.15)	
6 to 8	1591(31.49)	1517(95.83)	74(4.17)	
>8	1285(25.43)	1246(97.31)	39(2.69)	
Physical Activity				0.06
low	671(16.26)	649(97.87)	22(2.13)	
moderate	682(16.53)	661(96.28)	21(3.72)	
high	2773(67.21)	2691(97.73)	82(2.27)	

Table 2 Linear regression results of associations between CVD and MQI.total. Model 1 was analyzed without covariate adjusted; Model 2 adjusted with physical activity, Model 3 adjusted with sex, age, ethnicity, and physical activity; Model 4 was further adjusted with hypertension, diabetes, smoking status, alcohol use, educational level, poverty-income ratio (PIR), and body mass index (BMI), and daily sitting time. CVD, cardiovascular disease. BMI, body mass index. MQI.total, whole-body muscle quality index. CI, confidence interval. PIR, poverty-income ratio

	Model 1 Estimate (95% CI)	P value	Model 2 Estimate (95% CI)	P value	Model 3 Estimate (95% CI)	P value	Model 4 Estimate (95% CI)	P value
CVD								
No	Ref		Ref		Ref		Ref	
Yes	-0.28 (-0.40, -0.17)	< 0.0001	-0.21 (-0.31, -0.12)	< 0.0001	-0.15 (-0.24, -0.06)	0.002	-0.09 (-0.20, -0.02)	0.09

1: HR (95% CI)=0.59(0.43,0.81), $P<0.001$; Model 2: HR (95% CI)=0.68(0.51,0.90), $P=0.01$; Model 3: HR (95% CI)=0.74(0.55,0.99), $P=0.04$], although statistical significance was not achieved in the fully adjusted model 4 (shown in Table 3). In addition, the risk of CVD mortality increased with the decreased MQI.total values, shown in Table 3 [Model 1: HR (95% CI)=0.33(0.17,0.65), $P=0.001$; Model 2: HR (95% CI)=0.44(0.26,0.74), $P=0.002$; Model 3: HR (95% CI)=0.51(0.31,0.82), $P=0.01$]. However, after fully adjustment, the MQI.total values was not independently associated with CVD mortality [Model 4: HR (95% CI)=0.58(0.21,1.62), $P=0.3$]. In K-M analysis, participants with weaker muscle quality, especially those with extremely low MQI levels, exhibited the highest risk of all-cause and CVD mortality, although statistical significance was not achieved (shown in Supplementary Fig. 1).

Subgroup analyses of the association between MQI.total and CVD subtypes were shown in Table 4. After adjusting for physical activity (Model 2, Table 4), a negative association was found between MQI.total and individual CVDs, including angina and stroke [OR (95% CI)=0.64(0.41,0.99), $P=0.04$; OR (95% CI)=0.50(0.31,0.83), $P=0.01$, respectively). Importantly, MQI.total was significantly associated with congestive heart disease after adjusting for all covariates in model 4, [OR (95% CI)=0.35(0.18,0.68), $P=0.01$].

Discussion

To our knowledge, this study represents the first to use the MQI to investigate the relationship between muscle quality and the prevalence and mortality of CVD. According to the results of weighted linear and logistic multivariable regression analysis, although a weak negative correlation was observed between MQI.total and the prevalence of CVD, the fully adjusted model showed that low MQI.total did not predict the risk of CVD. In a study by Wu et al., sarcopenia, defined by low calf circumference, muscle strength, mass, and gait speed, was found to be associated with a higher risk of all-cause mortality [32]. Kitamura A et al. reported that Japanese older women and men meeting Asia criteria of sarcopenia had an increased risk of all-cause mortality [33]. A study enrolled 469,830 UK Biobank participants, sarcopenia, defined as slow gait speed and low muscle mass, was found to be associated with adverse outcomes, including the incidence and mortality of CVD, as well as all-cause mortality [34]. However, in our study, no association was observed between MQI.total and mortality after fully adjusting for potential confounders. Meanwhile, K-M analysis indicated that with the follow-up duration increased, individuals with poor muscle quality had a lower survival rate, although this did not reach statistical significance. Based on the current results, MQI.total was not a useful predictor for assessing the incidence

Table 3 Association of MQI total with the prevalence of CVD, all-cause mortality, and CVD-related mortality among US population, NHANES, 2011–2014. Model 1 was analyzed without covariate adjusted; Model 2 adjusted with physical activity; Model 3 adjusted with sex, age, ethnicity, and physical activity; Model 4 was further adjusted with hypertension, diabetes, smoking status, alcohol use, educational level, PIR, and BMI, and daily sitting time; CVD, cardiovascular disease; MQI: total, whole-body muscle quality index; BMI, body mass index; PIR, poverty-income ratio; CI, confidence interval

	Model 1 OR/HR(95%CI)	P-value	Model 2 OR/HR(95%CI)	P-value	Model 3 OR/HR(95%CI)	P-value	Model 4 OR/HR(95%CI)	P-value
CVD								
No	Ref		Ref		Ref		Ref	
Yes	0.47(0.35,0.63)	< 0.0001	0.55(0.42,0.72)	< 0.0001	0.65(0.50,0.84)	0.002	0.79(0.49,1.29)	0.31
All-cause mortality								
Alive	Ref		Ref		Ref		Ref	
Death	0.59(0.43,0.81)	< 0.0001	0.68(0.51,0.90)	0.01	0.74(0.55,0.99)	0.04	0.91(0.65,1.28)	0.59
CVD mortality								
No	Ref		Ref		Ref		Ref	
Yes	0.33(0.17,0.65)	0.001	0.44(0.26,0.74)	0.002	0.51(0.31,0.82)	0.01	0.58(0.21,1.62)	0.3

of CVD and mortality. These results may be attributed to MQI may have some limitations in assessing muscle quality, as it relies on a ratio of handgrip strength and muscle mass. In some cases, individuals with both lower handgrip strength and lower muscle mass may paradoxically exhibit a higher MQI value, making it challenging to accurately evaluate the relationship between muscle quality and health outcomes (CVD and mortality). In addition, older adults are prone to CVD and mortality due to the biologic underpinning of aging [35]. In previous studies, the majority of participants with poor muscle quality were older; however, our study exclusively enrolled middle-aged participants, potentially introducing selection bias.

Subgroup analysis was further conducted, revealing that participants with CHF were more likely to have low muscle quality than the normal participants, while there was no association between the MQI total and other individual CVDs in the fully adjusted model. Consequently, the MQI total indicator was more sensitive in predicting the prevalence of CHF. Despite many different clinical tests and techniques, there was still no broadly available standard for the diagnosis of muscle wasting. In this study, MQI was introduced as a novel indicator of muscle quality in an attempt to explore the relationship between muscle wasting and health outcomes. However, the fully adjusted models showed that low MQI total did not predict any health outcomes except for CHF. CHF is a systemic disease affecting approximately 2% of the population in the world [36, 37]. Muscle wasting has been considered as a frailty marker and has been linked to reduce survival in CHF patients [38]. Muscle wasting could induce ventilatory inefficiency and exercise intolerance in CHF patients [39]. The Studies Investigating Co-morbidities Aggravating Heart Failure (SICA-HF) enrolled 200 chronic HF patients and found that sarcopenia in HF patients with reduced ejection fraction was 20% higher than in healthy individuals [40]. Similarly, sarcopenia was also prevalent in HF patients with a preserved ejection fraction [41]. Therefore, it appears that muscle quality and CHF seem to be intertwined, affecting the progression and outcome of each other [42].

The significance of muscle quality in relation to cardiovascular health and overall well-being has garnered increasing recognition. Different from the well-known role of obesity in CVD and mortality (all-cause and CVD-related mortality), the impact of muscle quality on CVD risk and mortality is emerging and recognized nowadays. The underlying pathophysiologic mechanism between muscle quality and CVD risk and mortality is complex and needs further study. Based on the current study, chronic systemic inflammation plays a critical role in muscle wasting and deteriorating muscle quality, contributing to CVD and mortality [35]. Proinflammation

Table 4 Logistic regression was performed to study the associations of MQI.total with individual CVDs (Heart attack, Coronary heart disease, Angina, Congestive heart failure, Stroke) risk in US adults 2011–2014. Different models were adjusted by different covariables. CVD, cardiovascular disease. MQI.total, whole-body muscle quality index. CI, confidence interval

Individual CVD	Odds ratio (95% CI)	P-value
Heart attack		
Model 1	0.49(0.27,0.87)	0.02
Model 2	0.60(0.30,1.18)	0.13
Model 3	0.70(0.34,1.44)	0.31
Model 4	0.91(0.30,2.79)	0.86
Coronary heart disease		
Model 1	0.40(0.24,0.67)	< 0.001
Model 2	0.63(0.33,1.21)	0.16
Model 3	0.77(0.38,1.55)	0.44
Model 4	0.99(0.27,3.64)	0.99
Angina		
Model 1	0.48(0.25,0.92)	0.03
Model 2	0.64(0.41,0.99)	0.04
Model 3	0.76(0.49,1.18)	0.21
Model 4	1.06(0.45,2.49)	0.89
Congestive heart failure		
Model 1	0.24(0.13,0.44)	< 0.0001
Model 2	0.30(0.13,0.69)	0.01
Model 3	0.38(0.16,0.90)	0.03
Model 4	0.35(0.18,0.68)	0.01
Stroke		
Model 1	0.45(0.28,0.72)	0.002
Model 2	0.50(0.31,0.83)	0.01
Model 3	0.67(0.40,1.10)	0.11
Model 4	0.56(0.22,1.42)	0.19

cytokines such as interleukin(IL-6) and tumor necrosis factor- α (TNF- α) initiated muscle mitochondrial dysfunction, large amount of reactive oxygen species (ROS) production, leading to muscle proteolysis [35]. Meanwhile, risk factors of inflammation and oxidative stress for muscle health are also shared with CVD, leading to myostatin released from both myocytes and cardiomyocytes, establishing a vicious circle [43]. These findings provide evidence that ROS overload in muscles could initiate an inflammatory response that could affect the cardiovascular system.

In this study, we found that MQI for the whole body was negatively associated with CHF; thus, enhanced MQI level might reverse outcome. Physical exercise and nutrition intervention are two main strategies to improve MQI [35]. In Tang et al. study, they found that soy or whey protein consumption combined with moderate resistance exercise could be better than adopting either one individually to enhance muscle quality [44]. Additionally, oral testosterone supplementation has been shown to increase muscle mass and strength [45, 46], although its effect on CHF requires further investigation. Angiotensin-converting enzyme inhibitors (ACEIs), commonly used in CHF treatment, interestingly, not only improve cardiac function but also suppress inflammatory

responses and improve mitochondrial function, thereby reducing muscle catabolism [47]. Consequently, ACEI is one of the cornerstones for CHF treatment and it could improve muscle quality [35].

This exploratory analysis provided some insight into potential risk factors (low muscle mass, strength and quality) for CVD and mortality (all-cause and CVD-related mortality), especially for CHF. The major strength of this study is the large, representative sample size of the US population allowed us to fully understand the relationship between MQI and CVD, as well as mortality. In addition, the study has adjusted a wide range of potential covariables and used different statistical methods to minimize bias and validate the results. We employed MQI.total for a quantitative assessment of muscle quality, allowing for a more precise evaluation of the relationship between muscle quality and CHF. Consequently, subgroup analysis suggested that MQI was specifically associated with CHF, offering potential management strategies for these patients. However, we acknowledge that there are several limitations to this study. First, study showed that MQI was not very useful for predicting the health outcomes such as CVD and mortality. previous studies reported that the prevalence of sarcopenia, CVD and CVD mortality was high in the elderly group, while

this study only included 20-59-year-old participants due to incomplete exam information. Second, the outcome collection was based on self-reported, which might result in reporting bias. Further explore the association between MQI.app, MQI.arm and CVD was not performed in this study. Finally, the subgroup analysis couldn't investigate the correlation between MQI and arrhythmias due to the unavailability of this outcome in the NHANES database.

Conclusions

In conclusion, while MQI was not very useful for predicting the health outcomes such as CVD and mortality, a low MQI value has the potential to serve as a risk indicator for patients with CHF. Therefore, more attention should be paid to the early recognition of muscle weakness progression in CHF. Muscle weakness contributes to poor outcomes, thereby garnering public attention and motivating individuals to engage in appropriate resistance exercise, ultimately reducing the incidence of CVD and the mortality rate. However, further studies are needed to explore more effective indicator to evaluate the association between muscle quality and health outcomes.

Abbreviations

NHANES	National Health and Nutritional Examination Survey
NDI	National Death Index
NCHS	National Center for Health Statistics
MQI	Muscle quality index
CVD	Cardiovascular disease
MQIc.arm	Categorical value of muscle quality index for arms
MQIc.app	Categorical value of muscle quality index for four limbs
MQIc.total	Categorical value of whole-body muscle quality index
PIR	Poverty income ratio
MQI.total	Whole-body muscle quality index
MVPA	Moderate to vigorous aerobic physical activity
GPAQ	Global Physical Activity Questionnaire

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12889-023-17303-1>.

Supplementary Material 1

Acknowledgements

Not applicable.

Authors' contributions

YLC designed the study and wrote the manuscript. WDL, LF, HYL and SYJ collected and analyzed the data. XDY and SJP interpreted the data. YMX critically reviewed, edited and approved the manuscript. All authors reviewed and approved this manuscript.

Funding

This work was supported by the Guangdong Special Funds for science and Technology Innovation Strategy, China (Stability support for scientific research institutions affiliated with Guangdong Province-GDCI 2021).

Data Availability

The datasets used in this manuscript are publicly available from the NHANES website: <https://www.cdc.gov/nchs/nhanes/index.htm>.

Declarations

Ethics approval and consent to participate

This research analyzed data downloaded from the National Health and Nutrition Examination Survey public database. The National Center for Health Statistics Ethics Review Committee granted ethics approval. The methods performed in this study were in accordance with relevant guidelines and regulations (Declaration of Helsinki). All individuals signed informed consent before participating in the study. Details are available at <https://www.cdc.gov/nchs/nhanes/irba98.htm>.

Consent for publication

Not applicable.

Conflict of interest

The authors declare that they have no competing interests.

Author details

¹Department of Guangdong Cardiovascular Institute, Guangdong Provincial People's Hospital (Guangdong Academy of Medical Sciences), Southern Medical University, Guangzhou 510080, China

²The Second School of Clinical Medicine, Southern Medical University, Guangzhou 510515, China

³School of Medicine, South China University of Technology, Guangzhou 510006, China

Received: 7 July 2023 / Accepted: 22 November 2023

Published online: 01 December 2023

References

- Global regional. National age-sex specific mortality for 264 causes of death, 1980–2016: a systematic analysis for the global burden of Disease Study 2016. *Lancet* (London England). 2017;390(10100):1151–210.
- Virani SS, Alonso A, Benjamin EJ, Bittencourt MS, Callaway CW, Carson AP, Chamberlain AM, Chang AR, Cheng S, Delling FN, et al. Heart Disease and Stroke Statistics-2020 update: a Report from the American Heart Association. *Circulation*. 2020;141(9):e139–e596.
- Bell JA, Wade KH, O'Keefe LM, Carslake D, Vincent EE, Holmes MV, Timpson NJ, Davey Smith G. Body muscle gain and markers of Cardiovascular Disease susceptibility in young adulthood: a cohort study. *PLoS Med*. 2021;18(9):e1003751.
- Buckinx F, Landi F, Cesari M, Fielding RA, Visser M, Engelke K, Maggi S, Denison E, Al-Daghri NM, Allepaerts S, et al. Pitfalls in the measurement of muscle mass: a need for a reference standard. *J Cachexia Sarcopenia Muscle*. 2018;9(2):269–78.
- Kohara K, Okada Y, Ochi M, Ohara M, Nagai T, Tabara Y, Igase M. Muscle mass decline, arterial stiffness, white matter hyperintensity, and cognitive impairment: Japan Shimanami Health promoting Program study. *J Cachexia Sarcopenia Muscle*. 2017;8(4):557–66.
- Bielecka-Dabrowa A, Ebner N, Dos Santos MR, Ishida J, Hasenfuss G, von Haehling S. Cachexia, muscle wasting, and frailty in Cardiovascular Disease. *Eur J Heart Fail*. 2020;22(12):2314–26.
- Newsholme P, de Bittencourt PI Jr. The fat cell senescence hypothesis: a mechanism responsible for abrogating the resolution of inflammation in chronic Disease. *Curr Opin Clin Nutr Metab Care*. 2014;17(4):295–305.
- Fülster S, Tacke M, Sandek A, Ebner N, Tschöpe C, Doehner W, Anker SD, von Haehling S. Muscle wasting in patients with chronic Heart Failure: results from the studies investigating co-morbidities aggravating Heart Failure (SICA-HF). *Eur Heart J*. 2013;34(7):512–9.
- Tsuchida K, Fujihara Y, Hiroki J, Hakamata T, Sakai R, Nishida K, Sudo K, Tanaka K, Hosaka Y, Takahashi K, Oda H. Significance of Sarcopenia evaluation in Acute Decompensated Heart Failure. *Int Heart J*. 2018;59(1):143–8.
- Hajahmadi M, Shemshadi S, Khalilipour E, Amin A, Taghavi S, Maleki M, Malek H, Naderi N. Muscle wasting in young patients with dilated cardiomyopathy. *J Cachexia Sarcopenia Muscle*. 2017;8(4):542–8.
- Tian SL, Zhang K, Xu PC. Increased prevalence of peripheral arterial Disease in patients with obese sarcopenia undergoing hemodialysis. *Exp Ther Med*. 2018;15(6):5148–52.

12. Soysal P, Hurst C, Demurtas J, Firth J, Howden R, Yang L, Tully MA, Koyanagi A, Ilie PC, López-Sánchez GF, et al. Handgrip strength and health outcomes: Umbrella review of systematic reviews with meta-analyses of observational studies. *J Sport Health Sci*. 2021;10(3):290–5.
13. Barbat-Artigas S, Rolland Y, Zamboni M, Aubertin-Leheudre M. How to assess functional status: a new muscle quality index. *J Nutr Health Aging*. 2012;16(1):67–77.
14. Reinders I, Murphy RA, Koster A, Brouwer IA, Visser M, Garcia ME, Launer LJ, Siggeirsdottir K, Eiriksdottir G, Jonssson PV, et al. Muscle quality and muscle Fat Infiltration in Relation to Incident Mobility disability and gait speed decline: the Age, Gene/Environment susceptibility-Reykjavik Study. *J Gerontol A Biol Sci Med Sci*. 2015;70(8):1030–6.
15. Hairi NN, Cumming RG, Naganathan V, Handelsman DJ, Le Couteur DG, Creasey H, Waite LM, Seibel MJ, Sambrook PN. Loss of muscle strength, mass (Sarcopenia), and quality (specific force) and its relationship with functional limitation and physical disability: the Concord Health and Ageing in Men Project. *J Am Geriatr Soc*. 2010;58(11):2055–62.
16. Distefano G, Standley RA, Zhang X, Carnero EA, Yi F, Cornell HH, Coen PM. Physical activity unveils the relationship between mitochondrial energetics, muscle quality, and physical function in older adults. *J Cachexia Sarcopenia Muscle*. 2018;9(2):279–94.
17. Francis P, Toomey C, Mc Cormack W, Lyons M, Jakeman P. Measurement of maximal isometric torque and muscle quality of the knee extensors and flexors in healthy 50- to 70-year-old women. *Clin Physiol Funct Imaging*. 2017;37(4):448–55.
18. Yoda M, Inaba M, Okuno S, Yoda K, Yamada S, Imanishi Y, Mori K, Shoji T, Ishimura E, Yamakawa T, Shoji S. Poor muscle quality as a predictor of high mortality Independent of Diabetes in hemodialysis patients. *Biomed Pharmacother*. 2012;66(4):266–70.
19. Sui SX, Holloway-Kew KL, Hyde NK, Williams LJ, Tembo MC, Mohebbi M, Gojanovic M, Leach S, Pasco JA. Handgrip strength and muscle quality in Australian women: cross-sectional data from the Geelong osteoporosis study. *J Cachexia Sarcopenia Muscle*. 2020;11(3):690–7.
20. You Y, Chen Y, Zhang Q, Yan N, Ning Y, Cao Q. Muscle quality index is associated with trouble sleeping: a cross-sectional population based study. *BMC Public Health*. 2023;23(1):489.
21. Li B, Chen L, Hu X, Tan T, Yang J, Bao W, Rong S. Association of serum uric acid with all-cause and Cardiovascular Mortality in Diabetes. *Diabetes Care*. 2023;46(2):425–33.
22. Lopes LCC, Vaz-Gonçalves L, Schincaglia RM, Gonzalez MC, Prado CM, de Oliveira EP, Mota JF. Sex and population-specific cutoff values of muscle quality index: results from NHANES 2011–2014. *Clin Nutr*. 2022;41(6):1328–34.
23. Jones MT, Jagim AR, Haff GG, Carr PJ, Martin J, Oliver JM. Greater Strength drives difference in power between sexes in the Conventional Deadlift Exercise. *Sports (Basel Switzerland)* 2016, 4(3).
24. Lindle RS, Metter EJ, Lynch NA, Fleg JL, Fozard JL, Tobin J, Roy TA, Hurley BF. Age and gender comparisons of muscle strength in 654 women and men aged 20–93 year. *J Appl Physiol (Bethesda Md: 1985)*. 1997;83(5):1581–7.
25. Giovannucci EL, Rezende LFM, Lee DH. Muscle-strengthening activities and risk of Cardiovascular Disease, type 2 Diabetes, cancer and mortality: a review of prospective cohort studies. *J Intern Med*. 2021;290(4):789–805.
26. Young DR, Hivert MF, Alhassan S, Camhi SM, Ferguson JF, Katzmarzyk PT, Lewis CE, Owen N, Perry CK, Siddique J, Yong CM. Sedentary Behavior and Cardiovascular Morbidity and Mortality: A Science Advisory from the American Heart Association. *Circulation*. 2016;134(13):e262–279.
27. Bull FC, Maslin TS, Armstrong T. Global physical activity questionnaire (GPAQ): nine country reliability and validity study. *J Phys Act Health*. 2009;6(6):790–804.
28. Piercy KL, Troiano RP, Ballard RM, Carlson SA, Fulton JE, Galuska DA, George SM, Olson RD. The physical activity guidelines for americans. *JAMA*. 2018;320(19):2020–8.
29. Bao W, Liu B, Simonsen DW, Lehmler HJ. Association between exposure to pyrethroid insecticides and risk of all-cause and cause-specific mortality in the General US Adult Population. *JAMA Intern Med*. 2020;180(3):367–74.
30. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, Bauman A, Lee IM. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. *Lancet (London England)*. 2016;388(10051):1302–10.
31. Stamatakis E, Gale J, Bauman A, Ekelund U, Hamer M, Ding D. Sitting time, physical activity, and risk of mortality in adults. *J Am Coll Cardiol*. 2019;73(16):2062–72.
32. Wu SE, Chen WL. Calf circumference refines Sarcopenia in correlating with mortality risk. *Age Ageing* 2022, 51(2).
33. Kitamura A, Seino S, Abe T, Nofuji Y, Yokoyama Y, Amano H, Nishi M, Taniguchi Y, Narita M, Fujiwara Y, Shinkai S. Sarcopenia: prevalence, associated factors, and the risk of mortality and disability in Japanese older adults. *J Cachexia Sarcopenia Muscle*. 2021;12(1):30–8.
34. Petermann-Rocha F, Ho FK, Welsh P, Mackay D, Brown R, Gill JMR, Sattar N, Gray SR, Pell JP, Celis-Morales CA. Physical capability markers used to define Sarcopenia and their association with cardiovascular and respiratory outcomes and all-cause mortality: a prospective study from UK Biobank. *Maturitas*. 2020;138:69–75.
35. Damluji AA, Alfaraidhy M, AlHajri N, Rohant NN, Kumar M, Al Malouf C, Bahrainy S, Ji Kwak M, Batchelor WB, Forman DE, et al. Sarcopenia and Cardiovascular Diseases. *Circulation*. 2023;147(20):1534–53.
36. Crespo-Leiro MG, Anker SD, Maggioni AP, Coats AJ, Filippatos G, Ruschitzka F, Ferrari R, Piepoli MF, Delgado Jimenez JF, Metra M, et al. European Society of Cardiology Heart Failure Long-Term Registry (ESC-HF-LT): 1-year follow-up outcomes and differences across regions. *Eur J Heart Fail*. 2016;18(6):613–25.
37. Hao G, Wang X, Chen Z, Zhang L, Zhang Y, Wei B, Zheng C, Kang Y, Jiang L, Zhu Z, et al. Prevalence of Heart Failure and left ventricular dysfunction in China: the China Hypertension Survey, 2012–2015. *Eur J Heart Fail*. 2019;21(11):1329–37.
38. Lena A, Anker MS, Springer J. Muscle Wasting and Sarcopenia in Heart Failure-The Current State of Science. *Int J Mol Sci* 2020, 21(18).
39. Suzuki T, Palus S, Springer J. Skeletal muscle wasting in chronic Heart Failure. *ESC Heart Fail*. 2018;5(6):1099–107.
40. Emami A, Saitoh M, Valentova M, Sandek A, Evertz R, Ebner N, Loncar G, Springer J, Doehner W, Lainscak M, et al. Comparison of Sarcopenia and cachexia in men with chronic Heart Failure: results from the studies investigating co-morbidities aggravating Heart Failure (SICA-HF). *Eur J Heart Fail*. 2018;20(11):1580–7.
41. Tucker WJ, Haykowsky MJ, Seo Y, Stehling E, Forman DE. Impaired Exercise Tolerance in Heart Failure: role of skeletal muscle morphology and function. *Curr Heart Fail Rep*. 2018;15(6):323–31.
42. Yin J, Lu X, Qian Z, Xu W, Zhou X. New insights into the pathogenesis and treatment of Sarcopenia in chronic Heart Failure. *Theranostics*. 2019;9(14):4019–29.
43. Lee SJ, McPherron AC. Regulation of myostatin activity and muscle growth. *Proc Natl Acad Sci USA*. 2001;98(16):9306–11.
44. Tang JE, Moore DR, Kujbida GW, Tarnopolsky MA, Phillips SM. Ingestion of whey hydrolysate, casein, or soy protein isolate: effects on mixed muscle protein synthesis at rest and following resistance exercise in young men. *J Appl Physiol (Bethesda Md: 1985)*. 2009;107(3):987–92.
45. Srinivas-Shankar U, Roberts SA, Connolly MJ, O'Connell MD, Adams JE, Oldham JA, Wu FC. Effects of testosterone on muscle strength, physical function, body composition, and quality of life in intermediate-frail and frail elderly men: a randomized, double-blind, placebo-controlled study. *J Clin Endocrinol Metab*. 2010;95(2):639–50.
46. Storer TW, Basaria S, Traustadottir T, Harman SM, Pencina K, Li Z, Travison TG, Miciek R, Tsitouras P, Hally K, et al. Effects of Testosterone Supplementation for 3 years on muscle performance and physical function in older men. *J Clin Endocrinol Metab*. 2017;102(2):583–93.
47. Springer J, von Haehling S. ACE inhibitors and Sarcopenia: Covering all the BASEs? *Drugs Aging*. 2016;33(11):839–40.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.