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Prevalence and Trends of Sarcopenia Metrics and Related Body Composition: data from NHANES 1999-2006

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Abstract

Objective: Evaluate the prevalence and time trends of sarcopenia and related body composition over time.

Methods: Sarcopenia and sarcopenia components were defined according to the European Working Group on Sarcopenia. Logistic or linear regression models were used to evaluate the linear trend of the prevalence of sarcopenia, obesity, and body composition.

Setting: This is an analysis study of the data from NHANES (1999-2006).

Participants: A total of 29,947 participants aged 18 - 90 years from five waves of the NHANES were included in the analysis.

Outcome measures: Physical examinations were conducted in mobile examination centers. Body composition, including total body fat percentage, total body fat mass, total lean body mass, appendicular skeletal muscle mass (ASM) and bone mineral density (BMD) were measured by dual energy X-ray absorptiometry.

Results: The overall prevalence of sarcopenia ranged from 19.7% in 1999-2000 to 17.4% in 2005-2006 (P for trend=0.78). Sarcopenia in men decreased from 20.9% (95% CI: 18.0, 24.2) to 14.6% (95% CI: 12.2, 17.4) (P for trend=0.36); while in women, it increased from 18.2% to 20.6% (P for trend=0.20). Sarcopenia prevalence was significantly elevated among non-Hispanic blacks, increasing from 1.12% to 26.4% (P for trend < 0.001). Adults aged ⩾ 60 years old had the highest prevalence, but with a decrease trend over time (P for trend=0.28); while the sarcopenia in people aged less than 40 had raised slightly from 12.5% to 16.6% (P for trend=0.04).

Conclusions: The prevalence of sarcopenia has a youth-oriented tendency, and decreased in men but not in women. Non-Hispanic black and non-Hispanic white have reverse tendency.

Strengths and limitations of this study

- We used the data from nationally representative population-based surveys of the NHANES (1999-2006).
- We aimed to evaluate the prevalence of sarcopenia and found a youth-oriented tendency, and decreased in men but not in women.
- Body composition were measured by dual energy X-ray absorptiometry, which is the golden standard measurement for body composition.
- We only accessed muscle mass data rather than muscle strength which does not reflect muscle power and may be confounded by a third variable that was not involved in this study.
- We used a height adjusted definition of sarcopenia which is potentially problematic in identifying participants with sarcopenic obesity.

INTRODUCTION

According to the 2010 European Working Group on Sarcopenia in Older People, sarcopenia is defined as a cluster of geriatric conditions characterized by progressive and generalized loss of skeletal muscle mass and strength with a high risk of adverse outcomes including poor quality of life, physical disability, and even death.[1] The prevalence of sarcopenia among adults aged 55 years and older is high, affecting about 30-40% of those in long-term care.[2] It has been conservatively estimated sarcopenia affects more than 50 million people around the world and will increase by more than 200 million over the next 40 years.[3]

Sarcopenia is mainly caused by aging, decreased physical activities,[4] malnutrition[5 6] and endocrine and metabolic disorders.[7] These factors directly contribute to a loss of muscle mass and strength,[8] leading to a higher resting metabolic rate and reduced physical activity which often causes fat gain. The gained fat might mechanically result in a further loss of muscle mass and strength via cytokine protein catabolism[9] and insulin resistance.[10] Thus, sarcopenia and its effects can be part of a spiraling process of declining health.

Obesity and a sedentary lifestyle play key roles in the development of age-related sarcopenia. Recent data reported that obesity is affecting more people at a younger age due to physical inactivity.[11] Therefore, it is reasonable to hypothesize the prevalence of sarcopenia has increased accordingly. Currently, there is a lack of evidence to support this statement. Numerous studies have confirmed that sarcopenia increases the risk of frailty,[12] inflammation ,[13 14] liver fibrosis,[15 16] cirrhosis,[17 18] systemic sclerosis,[19] cancer,[20-22] chronic obstructive pulmonary disease,[23] cardiovascular disease (CVD),[24 25] and an elevated risk of mortality,[26] all of which, place considerable health and economic burden on public health care services. Thus, it is important to depict the prevalence and trends of sarcopenia and related body composition over time in relation to sex, age, and race to better inform public health policy and prevention strategies.

In this study, we reported the population-based prevalence and time trends of sarcopenia metrics, related body composition and cardiovascular fitness among adults in the United States (U.S.) from 1999 to 2006 using data from the National Health and Nutrition Examination Survey (NHANES).

METHODS

Study design and participants

The NHANES is a nationally representative cross-sectional survey among civilian non-institutionalized persons in the U.S..[27] This analytical study involved participants aged 18 years and older from the NHANES III cohort which ran from 1988-1994, followed by four consecutive cycles: 1999-2000, 2001-2002, 2003-2004, and 2005-2006. All NHANES protocols were approved by the National Center for Health Statistics Research ethics review board. All participants provided written informed consent.

Body component measurements and sarcopenia

Physical examinations were conducted in mobile examination centers. Weight in kilograms, height in centimeters, waist circumference (WC) in centimeters, and heart rate in beats per minute were measured using standardized techniques and equipment. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Overweight was defined as a BMI between 25.0-29.9 and obesity as a BMI of 30.0 or higher.[28] Central obesity was defined as having a WC of $>$ 102 cm for males and $>$ 88 cm for females.[29] Total body fat percentage, total body fat mass, total lean body mass, appendicular skeletal muscle mass (ASM) and bone mineral density (BMD) were measured using the dual energy X-ray absorptiometry (DXA) in the 1999-2006 surveys. Skeletal muscle mass index (SMI) was calculated as ASM divided by height squared (kg/m^2). Sarcopenia was sex-specifically defined as having a SMI of $\leq$ 7.26 kg/m^2 in men and $\leq$ 5.5 kg/m^2 in women.[30]

Physical activity and social-demographic factors

Participants' sex, age, race, education level, annual household income, time spent watching television per day, and level of physical activity were collected by household interviews. Age was grouped into three categories: 18 to 39 years old, 40 to 59 years old, and 60 years or older. Race was classified as non-Hispanic white, non-Hispanic black, Mexican American and others. Educational level was categorized into < high school graduate, high school graduate/general education development or ≥ college. Time spent watching TV per day was grouped into < 2h, 2–4h, or > 4h. Annual household income was grouped into < $25000, $25000 to $55000, or > $55000. Physical activity was grouped into two levels: moderate/below, or vigorous.

Statistical analyses

Participants' characteristics, including sex, age, race, education level, annual household income, time spent watching TV per day and level of physical activity were shown as unweighted frequency and a weighted percentage with a 95% confidence interval. Weighted mean and their 95% confidence intervals of weight, BMI and obesity, WC and central obesity, total body fat percentage, total lean body mass, ASM, SMI, BMD were calculated, and mean changes with 95% confidence intervals (CI) of all these variables from 1999-2000 to 2005-2006 were calculated.

The prevalence of sarcopenia was calculated for five survey cycles from 1999-2000 to 2005-2006 for the overall sample and the subgroups: sex, age group, race, education level, annual household income, time spent watching TV per day, and physical activity level. The interactions between different groups were compared using chi-square tests. The statistical significance of time trends among the overall sample and within the subgroups were assessed by survey-weighted linear (or logistic) regression models with survey year as a continuous

(ordered categorical) variable where appropriate.

Sampling weights were used to account for unequal probabilities of selection and nonresponses for all analyses, thereby providing estimates representative of the civilian, non-institutionalized U.S. population. All statistical analyses were performed using SAS for windows version 9.4 (SAS Institute, Cary, NC, USA). A two-sided $P < 0.05$ was considered as statistically significant.

Patient and public involvement

There was no patient or public involvement in this study.

RESULTS

There was a total of 14448 participants included in this study, 3,559 from 1999-2000, 4,047 from 2001-2002, 3,771 from 2003-2004, and 3,071 from 2005-2006 (**Table 1**). Distribution of participants' characteristics in the five survey cycles were comparable. In 1999-2000 ($n = 9$), 49.6% were women, 19.5% were 60 years or older, and 71.7% were Non-Hispanic white. And the proportion of those with a vigorous physical activity level significantly decreased from 1999 to 2006.

Table 1. Participants' characteristics (weighted) of participants from the NHANES surveys, 1999-2006

Characteristics	No. weighted (%)			
	1999-2000 (*n* = 3559)	2001-2002 (*n* = 4047)	2003-2004 (*n* = 3771)	2005-2006 (*n* = 3071)
Sex				
Men	1829 (50.4) [48.4, 52.5]	2106 (50.0) [48.6, 51.3]	1932 (49.5) [47.5, 51.6]	1574 (49.7) [48.0, 51.5]
Women	1730 (49.6) [47.5, 51.7]	1941 (50.0) [48.7, 51.4]	1839 (50.5) [48.4, 52.6]	1497 (50.3) [48.5, 52.0]
Age group, mean (SD) [95%CI]	43.3 (0.5) [42.1, 44.4]	43.6 (0.5) [42.5, 44.7]	44.2 (0.6) [43.0, 45.4]	41.4 (0.4) [40.5, 42.4]
18 – 39 yrs	1493 (47.3) [44.7 49.9]	1704 (44.0) [39.9, 48.1]	1592 (42.4) [38.5, 46.3]	1540 (44.9) [41.9, 47.8]
40 – 59 yrs	964 (33.2) [31.1 35.4]	1217 (38.2) [34.8, 41.7]	1015 (38.0) [34.7, 41.3]	1067 (43.8) [41.6, 46.4]
≥ 60 yrs	1102 (19.5) [16.9, 22.0]	1126 (17.8) [16.1, 19.5]	1164 (19.6) [17.7, 21.5]	464 (11.3) [9.33, 13.3]
Race				
Non-Hispanic white	1513 (71.7) [65.5, 77.9]	2014 (72.4) [67.5, 77.4]	1915 (73.2) [65.9, 80.5]	1321 (71.1) [65.1, 77.1]
Non-Hispanic black	642 (9.5) [6.25, 12.8]	785 (10.1) [6.9, 13.2]	796 (10.5) [6.6, 14.3]	128 (5.1) [3.4, 6.9]
Mexican American	1082 (6.6) [3.6, 9.5]	960 (7.7) [5.7, 9.7]	799 (7.7) [3.7, 11.7]	746 (8.90) [6.3, 11.5]
Others	322 (12.2) [5.8, 18.6]	288 (9.8) [5.8, 13.9]	261 (8.7) [6.3, 11.0]	876 (14.8) [10.9, 18.8]
Education level				
< High school graduate	1408 (23.6) [20.4, 26.7]	1300 (19.2) [17.0, 21.4]	1114 (17.8) [15.0, 20.5]	662 (15.5) [11.9, 19.2]
High school graduate/GED	840 (26.4) [22.4, 30.4]	980 (25.5) [23.3, 27.7]	978 (26.9) [24.7, 29.1]	618 (24.5) [22.1, 26.9]
≥ College	1302 (50.0) [45.8, 54.2]	1763 (55.3) [51.9, 58.7]	1675 (55.3) [52.0, 58.7]	1363 (60.0) [55.2, 64.9]
Family annual income				
< $25000	1452 (36.7) [29.6, 43.8]	1479 (29.7) [27.1, 32.3]	1518 (30.6) [26.7, 34.3]	920 (20.9) [17.6, 24.2]
$25000 – $55000	902 (30.8) [26.8, 34.8]	1163 (30.9) [27.5, 34.3]	1081 (32.0) [27.5, 36.5]	934 (30.6) [27.2, 34.1]
> $55000	731 (32.5) [26.7, 38.2]	1133 (39.4) [35.6, 43.1]	958 (37.4) [32.2, 42.7]	1097 (48.5) [43.6, 53.5]
Watching TV time per day, mean (SD) [95%CI]	2.34 (0.03) [2.28, 2.41]	2.31 (0.04) [2.24, 2.39]	2.16 (0.05) [2.06, 2.27]	2.07 (0.05) [1.97, 2.17]
< 2 h	621 (19.5) [17.7, 21.6]	606 (19.8) [17.9, 21.6]	634 (22.0) [19.3, 24.8]	545 (22.5) [20.8, 24.2]
2-4 h	2072 (68.3) [66.7, 69.9]	2215 (63.2) [61.4, 65.2]	2040 (64.7) [61.5, 67.9]	1674 (66.8) [65.0, 68.5]
> 4 h	428 (12.2) [10.7, 13.8]	674 (17.0) [15.6, 18.4]	542 (13.3) [10.7, 15.9]	354 (10.7) [8.49, 13.0]
Physical activity level				
Moderate or below	888 (44.0) [40.1, 47.8]	1236 (51.0) [47.0, 55.0]	1451 (61.5) [58.4, 64.6]	1066 (54.0) [51.0, 57.0]
Vigorous	1013 (56.0) [52.2, 59.9]	1253 (49.0) [45.0, 53.0]	963 (38.5) [35.5, 41.6]	1027 (46.0) [43.1, 49.0]

Prevalence and Trends of Sarcopenia from 1999 to 2006

The overall prevalence of sarcopenia ranged from 19.7% (95% CI: 18.1%, 21.4%) in 1999-2000 to 17.4% (95% CI: 14.9%, 20.2%) in 2005-2006 (*P* for trend = 0.78) (**Table 2)**.

The prevalence of sarcopenia in men decreased from 20.9% (95% CI: 18.0%, 24.2%) in 1999-2000 to 14.6% (95% CI: 12.2%, 17.4%) in 2005-2006 (*P* for trend = 0.36); while in women, the prevalence went from 18.2% in 1999-2000 to 20.6% in 2005-2006 (*P* for trend = 0.20). Sex differences were the largest in 2005-2006, 20.6% for women vs. 14.6% for men (*P* < 0.001). There were also racial differences in terms of sarcopenia prevalence as well as over time. It markedly increased from 1.12% in 1999-2000 to 26.4% in 2005-2006 among non-Hispanic blacks (*P* for trend < 0.001), but remained stable among non-Hispanic whites (21.7% in 1999-2000, 18.4% in 2005-2006; *P* for trend = 0.84) and Mexican Americans (17.1% in 1999-2000, 16.1% in 2005-2006; *P* for trend = 0.54) from 1999 to 2006. Participants aged ≥ 60 years had a significantly higher prevalence of sarcopenia in the four survey cycles from 1999-2006 compared to those aged 18–39 years old and 40–59 years old. In addition, participants who had high education levels, high family annual income, and vigorous physical activity levels were more likely to have relatively lower prevalence of sarcopenia compared to their corresponding lowest categories.

Table 2. Prevalence (95% CIs) and trends of sarcopenia in the NHANES surveys from 1999 to 2006

Characteristics	1999-2000 (n=3550)	2001-2002 (n=3987)	2003-2004 (n=3745)	2005-2006 (n=3062)	*P*-value for trend #
Overall	19.7 (18.1, 21.4)	19.5 (16.2, 23.5)	21.8 (19.4, 24.5)	17.4 (14.9, 20.2)	0.78
Sex					
Men	20.9 (18.0, 24.2)	18.5 (14.5, 23.5)	20.9 (17.9, 24.6)	14.6 (12.2, 17.4)	0.36
Women	18.2 (15.2, 21.7)	20.6 (16.7, 25.5)	22.8 (19.1, 27.3)	20.6 (16.7, 25.4)	0.20
P for sex	0.45	0.23	0.23	< 0.001	
Age group					
18 – 39 yrs	12.5 (9.5, 16.4)	15.6 (11.9, 20.4)	17.4, (15.6, 20.9)	16.6 (13.5, 20.3)	0.04
40 – 59 yrs	17.6 (14.7, 21.1)	13.6 (10.9, 16.9)	16.5 (13.1, 20.9)	14.3 (12.0, 17.1)	0.25
≥ 60 yrs	33.5 (28.8, 39.0)	35.1 (26.6, 46.3)	36.3 (30.7, 42.9)	22.0 (17.3, 27.9)	0.28
P for age group	< 0.001	< 0.001	< 0.001	0.05	
Race					
Non-Hispanic white	21.7 (19.4, 24.3)	19.5 (16.3, 23.2)	22.7 (19.5, 26.5)	18.4 (15.7, 21.6)	0.84
Non-Hispanic black	1.12 (0.42, 2.97)	6.52 (4.43, 9.60)	7.23 (4.96, 10.5)	26.4 (12.9, 54.3)	< 0.001
Mexican American	17.1 (14.4, 20.4)	18.3 (15.1, 22.1)	20.1 (16.5, 24.6)	16.1 (12.2, 21.1)	0.54
Others	19.0 (11.7, 30.7)	34.6 (21.1, 56.6)	37.0 (30.9, 44.3)	9.04 (6.17, 13.25)	0.13
P for Race	< 0.001	< 0.001	< 0.001	< 0.001	
Education level,					
< High school graduate	18.8 (14.5, 24.4)	20.5 (13.3, 31.6)	23.3 (18.8, 28.9)	19.1 (14.7, 24.8)	0.34
High school graduate or GED	19.8 (16.0, 24.6)	20.5 (15.6, 27.0)	20.4 (176, 23.8)	16.1 (12.6, 20.6)	0.47
≥ College	20.2 (18.2, 22.4)	18.2 (15.2, 21.8)	21.5 (17.4, 26.4)	15.8 (12.8, 19.5)	0.59
P for education	0.88	0.22	0.57	0.50	
Family annual income					
< $25000	21.6 (17.6, 26.6)	26.5 (18.8, 37.4)	29.7 (25.7, 34.3)	19.3 (15.2, 24.4)	0.51
$25000 – $55000	17.5 (14.1, 21.7)	19.9 (15.5, 25.7)	22.3 (18.1, 27.4)	16.4 (12.7, 21.3)	0.77
> $55000	17.6 (14.6, 21.2)	12.8 (9.56, 17.1)	16.7 (12.3, 22.7)	16.7 (12.7, 22.0)	0.94
P for income	0.17	0.005	< 0.001	0.80	
Watching TV time per day					
< 2 h	20.9 (14.6, 30.0)	19.8 (16.6, 23.6)	16.7 (11.8, 23.8)	13.5 (8.64, 21.0)	0.48
2-4 h	18.6 (169, 20.6)	20.5 (16.5, 25.4)	23.1 (19.7, 27.0)	17.0 (13.7, 21.1)	0.76
> 4 h	24.5 (16.7, 35.9)	20.1 (15.5, 25.9)	23.7 (17.4, 32.2)	15.8 (22.3, 22.2)	0.17
P for watching TV time	0.42	0.68	0.08	0.95	
Physical activity level					
Moderate or below	18.6 (16.1, 21.5)	23.0 (17.6, 30.0)	21.5 (17.9, 25.7)	17.4 (13.5, 22.3)	0.35
Vigorous	12.2 (9.42, 15.7)	13.6 (9.56, 19.4)	15.1 (10.0, 22.7)	13.2 (8.81, 19.6)	0.15
P for physical activity level	0.001	< 0.001	0.002	0.38	

Sarcopenia was defined according to DIA criteria; GED, general equivalency diploma. #: *P*-trend (1999-2006): adjusted for sex, age, race, education level, family annual income, watch TV time per day, and physical activity level.

Body Composition

The average bodyweight across all participants significantly increased from 76.8 kg (95% CI: 75.6, 77.9 kg) in 1999-2000 to 78.9 kg (95% CI: 77.4, 80.4 kg) in 2005-2006 (*P* for trend =0.010), an average increase of 2.11 kg (95%: 0.28, 3.93 kg) (**Table 3**). Correspondingly, the prevalence of obesity significantly increased from 24.3% to 29.3% in the overall population, from 20.8% (95% CI: 17.9%, 23.7%) to 27.6% (95% CI: 23.0%, 32.1%) in men (*P* for trend=0.007), and from 28.0% (95% CI: 24.2%, 31.9%) to 30.9% (95% CI: 27.4%, 34.5%) in women (*P* for trend=0.229), respectively (all *P-values* for trend < 0.001 (**Table 3 and Figure 1A**). After stratification by age (**Figure 1B**), obesity prevalence significantly increased from 21.9% to 24.0% in the 18-39 age group (*P* for trend =0.123, from 25.6% to 33.8% in the 40-59 age group (*P* for trend=0.027, and from 28.3% to 32.7% in the 60 years or older age group (*P* for trend=0.752), respectively. Similar trends of obesity prevalence were observed in non-Hispanic whites (from 23.8% to 28.6%, *P* for trend =0.024) and Mexican Americans (from 29.3% to 29.0%, *P* for trend = 0.632) but not in non-Hispanic blacks and the others group (**Figure 1C**). And from 1999-2000 to 2005-2006, We observed a large reduction in ASM and SMI (**Figure 2A**). Meanwhile, we observed a slight increase in the average waist circumference (**Figure 2B**), total lean body mass, prevalence of central obesity, and BMD (**Figure 2C**). The TPF in both non-Hispanic black and others were significantly increased (**Figure 2D**).

Table 3. Trends of body composition and cardiovascular fitness from 1999 to 2006 in the NHANES surveys

Characteristics	Survey cycles				*P* –trend #	Mean change from 1999-2000 to 2005-2006 (95% CI)
	1999-2000	2001-2002	2003-2004	2005-2006		
Weight, kg	76.8 (75.6, 77.9)	76.9 (76.1, 77.7)	78.3 (77.5, 79.0)	78.9 (77.4, 80.4)	0.010	2.11 (0.28, 3.93)
BMI, kg/m²	26.9 (26.5, 27.3)	26.8 (26.6, 27.1)	27.3 (27.0, 27.5)	27.5 (27.0, 28.0)	0.016	0.59 (-0.01, 1.20)
Overweight, % †	35.5 (32.6, 38.2)	36.7 (34.2, 39.3)	35.8 (32.9, 38.6)	34.1 (32.4, 35.9)	0.25	-1.31 (-4.45, 1.83)
Obesity, % †	24.3 (21.2, 27.4)	23.7 (21.3, 26.0)	27.6 (24.7, 30.5)	29.3 (25.8, 32.7)	0.023	4.92 (0.49, 9.36)
Waist Circumference, cm	92.6 (91.3, 93.9)	93.0 (92.4, 93.7)	94.9 (94.3, 95.5)	94.5 (93.1, 95.9)	<0.001	1.90 (0.12, 3.67)
Central obesity, % †	39.9 (35.3, 44.5)	41.5 (39.3, 43.8)	47.3 (44.5, 50.2)	45.1 (41.2, 49.1)	0.005	5.21 (-0.60, 11.0)
Total body fat percentage, %	33.0 (32.4, 33.7)	32.6 (32.3, 32.9)	33.5 (33.1, 34.0)	32.8 (32.3, 33.3)	0.766	-0.24 (-1.04, 0.56)
Total lean body mass, kg	49.3 (48.7, 49.8)	49.6 (49.1, 50.0)	49.8 (49.3, 50.3)	50.7 (50.0, 51.5)	<0.001	1.45 (0.57, 2.34)
ASM, kg *	21.7 (21.5, 22.0)	21.7 (21.4, 22.0)	21.7 (21.4, 21.9)	21.9 (21.6, 22.2)	0.986	0.16 (-0.24, 0.56)
SMI, kg/m²	7.53 (7.45, 7.61)	7.50 (7.41, 7.59	7.46 (7.38, 7.54)	7.55 (7.46, 7.64)	0.958	0.02 (-0.09, 0.14)
BMD, g/cm²	1.12 (1.11, 1.12)	1.14 (1.13, 1.14)	1.15 (1.14, 1.16)	1.17 (1.16, 1.19)	< 0.001	0.06 (0.04, 0.07)
Heart rate, beats/min	187 (186, 187)	186 (185, 187)	186 (185, 187)	--	0.15	-0.45 (-1.57, 0.66) [a]
VO_2max, ml/kg/min	40.4 (39.1, 41.8)	41.0 (40.3, 41.8)	39.4 (38.6, 40.2)	--	0.14	-1.02 (-2.52, 0.48) [a]
Low CVD fitness, % †	16.7 (12.6, 20.7)	12.9 (11.0, 14.8)	19.7 (16.3, 23.0)	--	0.51	3.03 (-1.99, 8.04) [a]

ASM: skeletal muscle mass, SMI: skeletal muscle index, BMD: bone mineral density; CVD: cardiovascular disease.

#: *P*-trend (1999-2006): adjusted for sex, age, race, education level, family annual income, watch TV time per day, and physical activity level.

a: For heart rate, VO_2max and low CVD fitness, the changes were from 1999-2000 to 2003-2004.

All statistics were weighted and shown as mean (95% confidence interval) or † percentage (95% confidence interval).

--: Not available.

DISCUSSION

Using nearly 20 years of nationally representative U.S. data from NHANES, we found the overall prevalence of sarcopenia remained stable between 1999 and 2006. However, stratification analyses revealed sarcopenia increased considerably among non-Hispanic blacks from 1999 to 2006. Obesity and central obesity significantly increased from 1999 to 2006. As anticipated, sarcopenia and its metrics increased accordingly in young people.

Sarcopenia and obesity have common environmental risk factors, including over-nutrition, metabolic disorders, and a sedentary lifestyle.[31] Obesity can lead directly to loss of muscle mass and strength,[32] and is commonly accompanied with a reduction in physical activity and the promotion of metabolic disorders, which in turn, accelerates abnormal distribution of fat mass and initiates the process of sarcopenia.[33] Our study reveals an increasing trend in obesity prevalence across all three age groups. A significant elevation in the prevalence of sarcopenia from 1999 to 2006 was observed in the young (18-39 years) age group. The peak period of skeletal muscle mass is around 20 years old which begins to decreases at around 30 years old.[34] The peak period of muscle strength lags nearly 10-years behind the peak period of muscle mass and starts to decline at around 50 years old.[35] The speed of declination of muscle strength is 2 to 5 times faster than that of muscle mass over the same period of time.[36] However, it is still unclear whether muscle mass reduction at a young age would further accelerate muscle strength loss and ageing related health issues. Observational studies reported a linearly positive association between muscle mass and strength in both middle aged and elderly people.[37-39] This indicates the higher the amount of muscle mass acquired during a young age may protect adults from the early onset of sarcopenia. Therefore, it may be beneficial for prevention and intervention strategies to pay more attention to increasing muscle mass in both young and old populations.

We did not observe significant sex differences over time in relation to sarcopenia

prevalence. From 1999 to 2006, sarcopenia prevalence decreased in men but not in women. Previous evidence is controversial and inconsistent. Michele *et al.* compared 195 women aged 64 to 93 years old and 142 men aged 64 to 92 years old, they found a higher prevalence of sarcopenia in men than in women;[40] while in the Fifth Korea National Health and Nutrition Examination Survey, sarcopenia was more prevalent in women.[41] Women have less absolute and relative muscle mass than men[42] in biology. Besides natural differences in skeletal muscle between men and women, such as the amount of muscle mass, muscle capillary density, and muscle fiber type,[43] physical activity might be a potential cause for sex differences in sarcopenia prevalence.[44] In our study, most women had lower self-reported levels of physical activity than men. The amount of physical activity in men gradually increased, whereas it decreased in women over time. Another critical factor is age-related changes in the gonadal function and sex hormones regulating muscle mass distribution. Evidence suggested lower serum testosterone levels in elderly men contributes to muscle weakness.[45] Men experience a gradual decrease in knee extensor and handgrip strength between 20 and 80 years of age, whereas, women experience a steep decline after the age of 55 (menopausal age).[46 47] Although it is not clear whether age-related changes in the gonadal function directly regulate physical activity in humans, animals after gonadectomy can cause a dramatical decline in spontaneous physical activity.[48] Thus, sex differences might be pivotal in understanding the process of sarcopenia and aging, understanding why each sex remains "muscle healthy" throughout their lifespan could open new avenues to prevent and treat sarcopenia and the ageing process.

We also detected an increased trend of sarcopenia prevalence, from 1.12% in 1999 to 26.4% in 2006, in non-Hispanic black people, while the prevalence was stable in non-Hispanic Whites, Mexican Americans and other racial groups over time. Racial differences in muscle mass have been reported in previous studies. Evidence has shown African-Americans

have significantly higher skeletal muscle/adipose tissue-free body mass ratio than other races, although the difference was very small.[49] Mahbubur and Abbey reported black women had greater levels of total and regional lean mass than White and Hispanic women, while Hispanic women had even lower values than white women after assessment of body composition of 708 healthy black, white, and Hispanic women aged 16–33 years using DXA analysis.[50] According to the NHANES III bioelectrical impedance data, the amount of fat-free mass in Mexican-Americans was lower than in non-Hispanic Blacks, which was lower than in non-Hispanic Whites.[51] The underlying mechanism of racial differences is still unclear and warrants further investigation.

There are several limitations of this study. First, we only accessed muscle mass data rather than muscle strength which does not reflect muscle power and may be confounded by a third variable that was not involved in this study. Second, the prevalence of sarcopenia in women may be underestimated because we used a height adjusted definition of sarcopenia[52] which is potentially problematic in identifying participants with sarcopenic obesity.[53] However, if we had used the weight-adjusted definition, people classified as having sarcopenia would have had higher BMI values compared with those without sarcopenia.[54] Third, physical activity data was self-reported therefore bias may be a factor. Recent research on self-reported levels of physical activity indicated individuals in the U.S. tended to have differing perceptions of activity levels, overestimating their time spent exercising compared to Europeans.[55] Future studies should apply objective measures to muscle strength and physical activity to accurately evaluate sarcopenia prevalence.

CONCLUSIONS

Using data from the representative NHANES surveys covering nearly 20 years of data from 1999 to 2006, there was a youth-oriented tendency of prevalence of sarcopenia from

1999 to 2006 among U.S. adults. Sarcopenia prevalence significantly decreased in men but not in women from 1999 to 2006. Together with an increase in obesity and central obesity, elevations of sarcopenia in non-Hispanic blacks and young people were observed. It is recommended to control body fat ratio and develop good habit of keeping resistant and moderate physical activity to prevent sarcopenia both for young and elderly people. The continued high prevalence of sarcopenia and obesity is an important public health concern.

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Contributiors

JL and XZ designed and conducted the research; JL and XZ analyzed data; JL, XZ, YW and DG are responsible for the final content of the manuscript; all authors took part in writing the manuscript, read and approved the final version.

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Competing interests

No declared.

Patient consent for publication

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Ethics approval

All NHANES protocols were approved by the National Center for Health Statistics Research ethics review board.

Data availability statement

The data link is https://www.cdc.gov/nchs/nhanes/index.htm.

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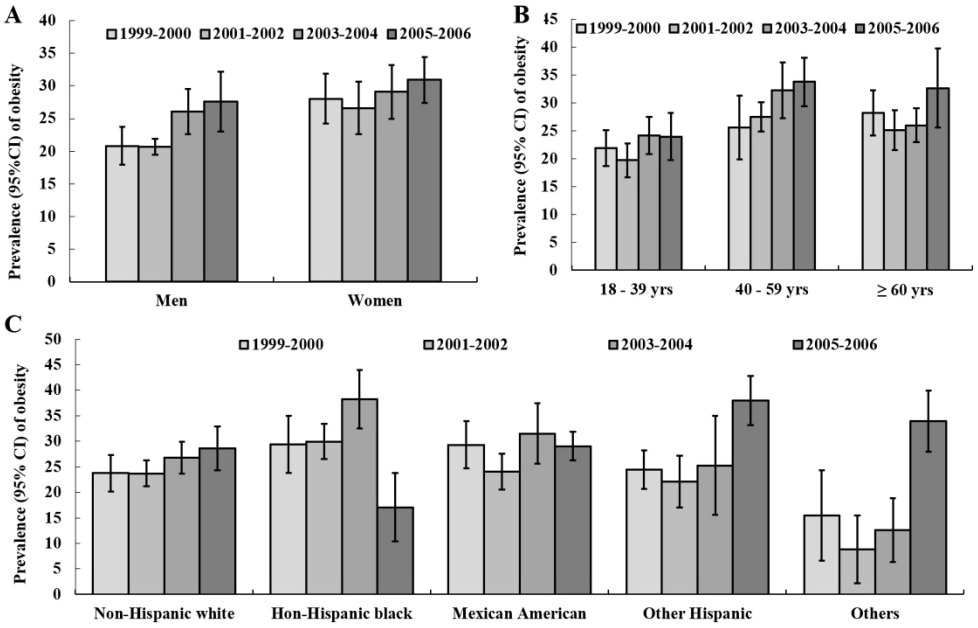
Figure Legends

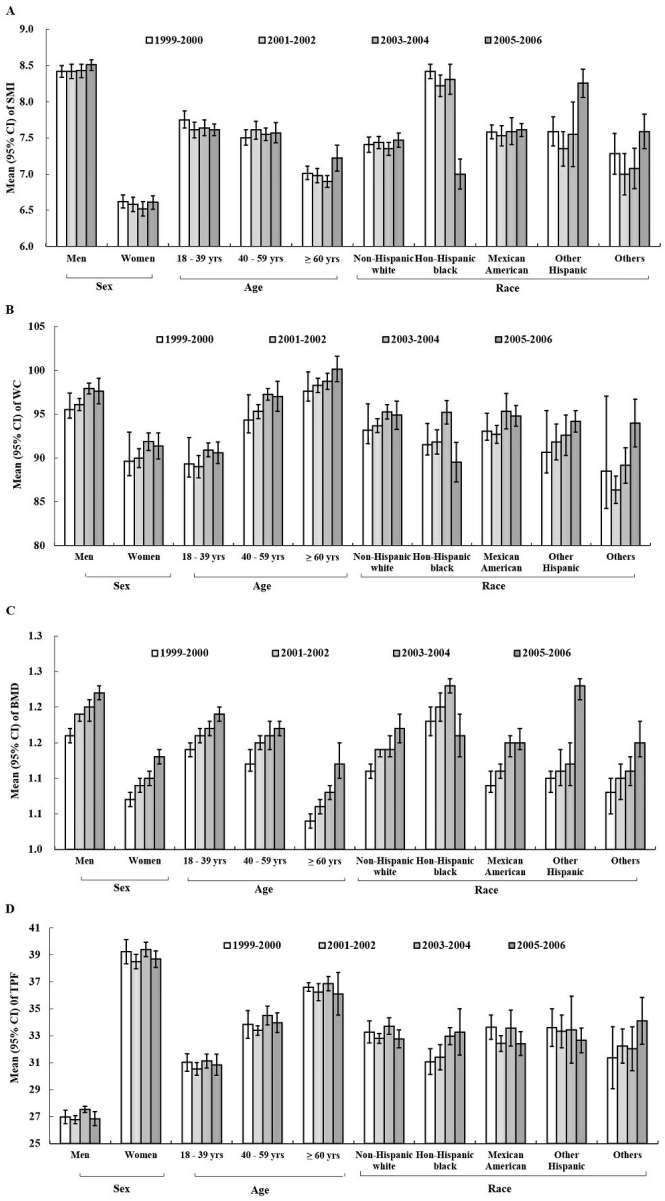
Figure 1. Prevalence of obesity stratified by sex (A), age (B) and race groups (C) from 1988 to 2006 in the NHANES surveys

Figure 2. Distribution of body compositions, including SMI (A), WC (B), BMD (C), and TPF (D) by sex, age and race group from 1999 to 2006



Prevalence of obesity stratified by sex (A), age (B) and race groups (C) from 1988 to 2006 in the NHANES surveys

382x255mm (200 x 200 DPI)



Distribution of body compositions, including SMI (A), WC (B), BMD (C), and TPF (D) by sex, age and race group from 1999 to 2006

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Prevalence and Temporal Trends of Pre-sarcopenia Metrics and Related Body Compositions from a longitudinal data of 1999-2006 NHANES survey

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Abstract

Objective: Evaluate the prevalence and temporal trends of pre-sarcopenia and related body compositions.

Study design and Setting: This is an analysis study of the longitudinal data from 1999-2006 National Health and Nutrition Examination Survey (NHANES).

Methods: Presarcopenia was defined according to the European Working Group on Sarcopenia. Logistic or linear regression models were used to evaluate the linear trend of the prevalence of presarcopenia, obesity, and related body compositions.

Participants: A total of 29,947 participants aged 18 - 90 years from five waves of the NHANES were included in the analysis.

Outcome measures: Pre-sarcopenia was sex-specifically defined as having a skeletal mass index ≤ 7.26 kg/m^2 in men and ≤ 5.5 kg/m^2 in women. Body compositions, including total body fat percentage, total body fat mass, total lean body mass, appendicular skeletal muscle mass (ASM) and bone mineral density (BMD) were measured by dual energy X-ray absorptiometry.

Results: The overall prevalence of pre-sarcopenia ranged from 16.4% in 1999-2000 to 14.8% in 2005-2006 (P for trend=0.78). Pre-sarcopenia were stable in both males (*P* for trend=0.36) and females (P for trend=0.20). Pre-sarcopenia prevalence was significantly elevated among 18 – 39 years age group (from 11.3% to 14.1%, P for trend = 0.04) and among non-Hispanic blacks (from 6.2% to 20.6%, *P* for trend < 0.001). Adults aged ⩾ 80 years old had the highest prevalence.

Conclusions: The prevalence of pre-sarcopenia has a trend toward youth, and remained stable over time. Non-Hispanic black has an increasing trend over time.

Keywords: Pre-sarcopenia Metrics; Body Composition; Temporal Trends.

Strengths and limitations of this study

- We used the longitudinal data from nationally representative population-based surveys of the NHANES (1999-2006).
- Body composition were measured by the golden standard of dual energy X-ray absorptiometry.
- Appendicular skeletal muscle mass rather than muscle strength and physical performance was assessed.
- The prevalence of pre-sarcopenia in women may be underestimated when used a height adjusted definition of pre-sarcopenia.
- Reporting bias may exist due to self-reported physical activity data.

INTRODUCTION

According to the 2010 European Working Group on Sarcopenia in Older People (EWGSOP), sarcopenia is defined as a cluster of geriatric conditions characterized by progressive and generalized loss of skeletal muscle mass and strength with a high risk of adverse outcomes including poor quality of life, physical disability, and even death.[1] The prevalence of pre-sarcopenia (52.7% in men and 25.3% in female) and sarcopenia (20.7% in men and 15.3% in female) among adults aged 55 years and older are high, affecting about 30-40% of those in long-term care.[2] It has been conservatively estimated that sarcopenia affects more than 50 million people around the world and will increase by more than 200 million over the next 40 years.[3]

Currently, there is a variety of but no consensus definition for sarcopenia, and its prevalence is highly dependent on the diagnostic criteria used in the study. Among all three components of sarcopenia based on EWGSOP, muscle mass, muscle strength, and performance, muscle mass play a critical role in the progress of sarcopenia, and low muscle mass has been identified as pre-sarcopenia. Sarcopenia, especially low skeletal muscle is mainly caused by aging, decreased physical activities,[4] malnutrition,[5 6] and endocrine and metabolic disorders.[7] These factors directly contribute to a loss of muscle mass,[8] influencing the muscle strength and performance, leading to a lower metabolic rate and reduced physical activity which often causes fat gain. The gained fat might mechanically result in a further loss of muscle mass and strength via cytokine protein catabolism[9] and insulin resistance.[10] Thus, sarcopenia and its effects can be part of a spiraling process of declining health.

Obesity and sedentary lifestyle play key roles in the development of age-related muscle reduce. Sarcopenic obesity, defined as lose in lean body mass but preservation or even increase in body fat mass, is one of the conditions which has serious health implications. Recent data reported that obesity is affecting more people at a younger age due to physical inactivity.[11]

Therefore, it is reasonable to hypothesize that the prevalence of pre-sarcopenia has increased accordingly. Currently, there is a lack of evidence to support this statement. Numerous studies have confirmed that sarcopenia increases the risk of frailty,[12] inflammation ,[13 14] liver fibrosis,[15 16] cirrhosis,[17 18] systemic sclerosis,[19] cancer,[20-22] chronic obstructive pulmonary disease,[23] cardiovascular disease (CVD),[24 25] and mortality,[26] all of which place considerable health and economic burden on public health care services. Thus, it is important to depict the prevalence and trends of pre-sarcopenia and related body compositions over time in relation to sex, age, and race to better inform public health policy and prevention strategies.

In this study, we estimated the population-based prevalence and temporal trends of pre-sarcopenia metrics and related body compositions among adults in the United States (U.S.) from 1999 to 2006 using data from the National Health and Nutrition Examination Survey (NHANES).

METHODS

Study design and participants

The NHANES is a nationally representative cross-sectional survey among civilian non-institutionalized persons in the U.S..[27] This analytical study involved participants aged 18 years and older from the NHANES cohort of four consecutive cycles: 1999-2000 (*n*=3,559), 2001-2002 (*n*=4,047), 2003-2004 (*n*=3,771), and 2005-2006 (*n*=3,071). All NHANES protocols were approved by the National Center for Health Statistics Research ethics review board. All participants provided written informed consent.

Body component measurements and pre-sarcopenia

Physical examinations were conducted in mobile examination centers. Weight in kilograms, height in centimeters, and waist circumference (WC) in centimeters were measured

using standardized techniques and equipment. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Overweight was defined as a BMI between 25.0-29.9 and obesity as a BMI of 30.0 or higher.[28] Central obesity was defined as having a WC of > 102 cm for males and > 88 cm for females.[29] Total body fat percentage, total body fat mass, total lean body mass, appendicular skeletal muscle mass (ASM) and bone mineral density (BMD) were measured using the dual energy X-ray absorptiometry (DXA) in the four surveys from 1999 to 2006. Skeletal muscle mass index (SMI) was calculated as ASM divided by height squared (kg/m^2). Pre-sarcopenia was sex-specifically defined as having a SMI $\leq$ 7.26 kg/m^2 in men and $\leq$ 5.5 kg/m^2 in women.[30]

Cardiovascular fitness

Cardiovascular fitness was examined using treadmill test. Participants were assigned to one of eight protocols, according to their gender, age, BMI, and self-reported levels of physical activity. Each protocol included a 2-minute warm-up, two 3-minute exercise stages, and a 2-minute cool-down period [31]. The goal of each protocol was to elicit a heart rate that was approximately 80% of the age-predicted maximum (220-age) by the end of the second exercise stage. The heart rate was monitored continuously via 4 electrodes connected to the trunk and abdomen of the participant, and it was recorded at the end of warm-up, each exercise stage, and each minute of recovery. VO2max (mL/kg/minute) was estimated by extrapolation to an expected age-specific maximal heart rate by using measured heart rate responses to the two 3-minute exercise stages [32, 33].

Physical activity and social-demographic factors

Participants' sex, age, race, education level, annual household income, time spent watching television per day, and level of physical activity were collected by household interviews. Age was grouped into three categories: 18 to 39 years old, 40 to 59 years old, and 60 years or older. Race was classified as non-Hispanic white, non-Hispanic black, Mexican

American, and others. Educational level was categorized into < high school graduate, high school graduate/general equivalency diploma, or ≥ college. Time spent watching TV per day was grouped into < 2h, 2–4h, or > 4h. Annual household income was grouped into < $25000, $25000 to $55000, or > $55000. Physical activity was grouped into two levels: moderate/below, or vigorous.

Statistical analyses

Participants' characteristics, including sex, age, race, education level, annual household income, time spent watching TV per day and level of physical activity, were shown as unweighted frequency and weighted percentage with 95% confidence interval. Weighted mean and corresponding 95% confidence intervals of body weight, BMI and obesity, WC and central obesity, total body fat percentage, total lean body mass, ASM, SMI, BMD were calculated, and mean changes with 95% confidence intervals (CI) of all these variables from 1999-2000 to 2005-2006 were calculated.

The age- and sex-adjusted prevalence of pre-sarcopenia was calculated for four survey cycles from 1999-2000 to 2005-2006 among overall sample and the subgroups by sex, age, race, education level, annual household income, time spent watching TV per day, and physical activity level. The interactions between different groups were compared using chi-square tests. The temporal trends of pre-sarcopenia prevalence and body compositions among overall sample and within the subgroups were assessed by survey-weighted linear (for continuous outcomes) or logistic (for binary outcomes) regression models with survey year as a continuous (ordered categorical) independent variable.

Sampling weights were used to account for unequal probabilities of selection and nonresponses for all analyses, thereby providing estimates representative of the civilian, non-institutionalized U.S. population. All statistical analyses were performed using SAS for

windows version 9.4 (SAS Institute, Cary, NC, USA). A two-sided $P < 0.05$ was considered as statistically significant.

Patient and public involvement

There was no patient or public involvement in this study.

RESULTS

A total of 14,448 participants were included in this study, with 3,559 from 1999-2000, 4,047 from 2001-2002, 3,771 from 2003-2004, and 3,071 from 2005-2006 (**Table 1**). Distribution of participants' characteristics in the four survey cycles were comparable. In 1999-2000, 49.6% were women, 19.5% were 60 years or older, and 71.7% were Non-Hispanic white. The proportion of those with a vigorous physical activity level showed a significantly decreased trend from 1999 to 2006 (p <0.001).

187 **Table 1. Participants' characteristics (weighted) from the NHANES surveys, 1999-2006**

Characteristics	No. weighted (%)			
	1999-2000 (*n* = 3559)	2001-2002 (*n* = 4047)	2003-2004 (*n* = 3771)	2005-2006 (*n* = 3071)
Sex				
Men	1829 (50.4) [48.4, 52.5]	2106 (50.0) [48.6, 51.3]	1932 (49.5) [47.5, 51.6]	1574 (49.7) [48.0, 51.5]
Women	1730 (49.6) [47.5, 51.7]	1941 (50.0) [48.7, 51.4]	1839 (50.5) [48.4, 52.6]	1497 (50.3) [48.5, 52.0]
Age group, mean (SD) [95%CI]	43.3 (0.5) [42.1, 44.4]	43.6 (0.5) [42.5, 44.7]	44.2 (0.6) [43.0, 45.4]	41.4 (0.4) [40.5, 42.4]
18 – 39 yrs	1493 (47.3) [44.7 49.9]	1704 (44.0) [39.9, 48.1]	1592 (42.4) [38.5, 46.3]	1540 (44.9) [41.9, 47.8]
40 – 59 yrs	964 (33.2) [31.1 35.4]	1217 (38.2) [34.8, 41.7]	1015 (38.0) [34.7, 41.3]	1067 (43.8) [41.6, 46.4]
60– 79yrs	913 (17.1) [14.7, 19.4]	887 (15.2) [13.8, 16.7]	915 (16.7) [15.1, 18.3]	464 (11.3) [9.3, 13.3]
≥ 80 yrs	189 (2.4) [1.9, 2.8]	239 (2.6) [2.1, 2.0]	249 (2.9) [2.2. 3.5]	--
Race				
Non-Hispanic white	1513 (71.7) [65.5, 77.9]	2014 (72.4) [67.5, 77.4]	1915 (73.2) [65.9, 80.5]	1321 (71.1) [65.1, 77.1]
Non-Hispanic black	642 (9.5) [6.25, 12.8]	785 (10.1) [6.9, 13.2]	796 (10.5) [6.6, 14.3]	128 (5.1) [3.4, 6.9]
Mexican American	1082 (6.6) [3.6, 9.5]	960 (7.7) [5.7, 9.7]	799 (7.7) [3.7, 11.7]	746 (8.90) [6.3, 11.5]
Others	322 (12.2) [5.8, 18.6]	288 (9.8) [5.8, 13.9]	261 (8.7) [6.3, 11.0]	876 (14.8) [10.9, 18.8]
Education level				
< High school graduate	1408 (23.6) [20.4, 26.7]	1300 (19.2) [17.0, 21.4]	1114 (17.8) [15.0, 20.5]	662 (15.5) [11.9, 19.2]
High school graduate/GED	840 (26.4) [22.4, 30.4]	980 (25.5) [23.3, 27.7]	978 (26.9) [24.7, 29.1]	618 (24.5) [22.1, 26.9]
≥ College	1302 (50.0) [45.8, 54.2]	1763 (55.3) [51.9, 58.7]	1675 (55.3) [52.0, 58.7]	1363 (60.0) [55.2, 64.9]
Family annual income				
< $25000	1452 (36.7) [29.6, 43.8]	1479 (29.7) [27.1, 32.3]	1518 (30.6) [26.7, 34.3]	920 (20.9) [17.6, 24.2]
$25000 – $55000	902 (30.8) [26.8, 34.8]	1163 (30.9) [27.5, 34.3]	1081 (32.0) [27.5, 36.5]	934 (30.6) [27.2, 34.1]
> $55000	731 (32.5) [26.7, 38.2]	1133 (39.4) [35.6, 43.1]	958 (37.4) [32.2, 42.7]	1097 (48.5) [43.6, 53.5]
Watching TV time per day, mean (SD) [95%CI]	2.34 (0.03) [2.28, 2.41]	2.31 (0.04) [2.24, 2.39]	2.16 (0.05) [2.06, 2.27]	2.07 (0.05) [1.97, 2.17]
< 2 h	621 (19.5) [17.7, 21.6]	606 (19.8) [17.9, 21.6]	634 (22.0) [19.3, 24.8]	545 (22.5) [20.8, 24.2]
2-4 h	2072 (68.3) [66.7, 69.9]	2215 (63.2) [61.4, 65.2]	2040 (64.7) [61.5, 67.9]	1674 (66.8) [65.0, 68.5]
> 4 h	428 (12.2) [10.7, 13.8]	674 (17.0) [15.6, 18.4]	542 (13.3) [10.7, 15.9]	354 (10.7) [8.49, 13.0]
Physical activity level				
Moderate or below	888 (44.0) [40.1, 47.8]	1236 (51.0) [47.0, 55.0]	1451 (61.5) [58.4, 64.6]	1066 (54.0) [51.0, 57.0]
Vigorous	1013 (56.0) [52.2, 59.9]	1253 (49.0) [45.0, 53.0]	963 (38.5) [35.5, 41.6]	1027 (46.0) [43.1, 49.0]
Body mass index				
Normal or below (< 25 kg/m^2)	1351 (40.1) [36.3, 43.9]	1617 (39.6) [38.0, 41.2]	1389 (36.6) [34.6, 38.6]	1089 (36.6) [33.1, 40.2]

Overweight (25.0-29.9 kg/m²)	1289 (35.5) [32.7, 38.3]	1494 (36.7) [34.2, 39.3]	1348 (35.8) [32.9, 38.6]	1054 (34.1) [32.4, 35.9]
Obesity (≥ 30 kg/m²)	914 (24.4) [21.3, 27.5]	936 (23.7) [21.3, 26.0]	1034 (27.6) [24.7, 30.5]	928 (29.3) [25.8, 32.7]

Prevalence and temporal trends of pre-sarcopenia from 1999 to 2006

The overall age- and sex-adjusted prevalence of pre-sarcopenia ranged from 16.4% (95% CI: 18.1%, 21.4%) in 1999-2000 to 14.8% (95% CI: 14.9%, 20.2%) in 2005-2006 (*P* for trend = 0.78) (**Table 2)**.

The age- and sex-adjusted prevalence of pre-sarcopenia in men decreased from 22.7% (95% CI: 20.3%, 25.2%) in 1999-2000 to 12.3% (95% CI: 10.6%, 14.3%) in 2005-2006 (*P* for trend = 0.36); while in women, the prevalence went from 20.0% in 1999-2000 to 17.7% in 2005-2006 (*P* for trend = 0.20). Sex differences were the largest in 2005-2006, 12.3% for men vs. 17.7% for women ($P < 0.001$). There were also racial differences of pre-sarcopenia prevalence as well as temporal trend. It significantly increased from 6.2% in 1999-2000 to 20.6% in 2005-2006 among non-Hispanic blacks (*P* for trend < 0.001), but remained stable among non-Hispanic whites (*P* for trend = 0.84) and Mexican Americans (*P* for trend = 0.54) from 1999 to 2006. Participants aged ≥ 80 years and 60 – 79 years had a significantly higher prevalence of sarcopenia in the four survey cycles from 1999-2004 compared to those aged 18–39 years old and 40–59 years old. In three survey cycles of 1999-2000, 2001-2002, and 2003-2004, participants who had vigorous physical activity levels were more likely to have relatively lower prevalence of pre-sarcopenia compared to the lowest categories (p values < 0.01). In addition, participants with higher family annual income had a lower prevalence of pre-sarcopenia in survey cycles of 2001-2002 and 2003-2004. In all four survey cycles, participants with BMI < 25 kg/m2 has a relatively higher prevalence of pre-sarcopenia as compare with overweight and obese participants.

Table 2. Prevalence (95% CIs) and temporal trends of pre-sarcopenia in the NHANES surveys from 1999 to 2006

Characteristics	1999-2000 (n=3550)	2001-2002 (n=3987)	2003-2004 (n=3745)	2005-2006 (n=3062)	*P*-value for trend #
Overall	16.4 (15.3, 17.6)	16.4 (14.0, 19.1)	17.9 (16.2, 19.7)	14.8 (13.0, 16.8)	0.78
Sex					
Men	22.7 (20.3, 25.2)	19.7 (15.9, 24.2)	21.2 (18.8, 23.7)	12.3 (10.6, 14.3)	0.36
Women	20.0 (17.9, 22.3)	21.4 (17.7, 25.5)	23.0 (19.8, 26.6)	17.7 (14.9, 20.9)	0.20
***P* for sex**	0.45	0.23	0.23	< 0.001	
Age group					
18 – 39 yrs	11.3 (9.1, 14.0)	13.5 (10.6, 17.0)	14.9 (12.8, 17.3)	14.1 (11.8, 16.8)	0.04
40 – 59 yrs	15.1 (12.9, 17.5)	12.1 (9.9, 14.7)	14.2 (11.6, 17.2)	12.9 (11.0, 15.2)	0.25
60 – 79 yrs	22.3 (19.0, 26.1)	23.7 (18.7, 29.6)	23.6 (20.3, 27.2)	17.7 (14.4, 21.5)	0.38
≥ 80 yrs	45.1 (38.7, 51.6)	40.1 (31.8, 49.0)	42.0 (36.2, 48.0)	--	0.64
***P* for age group**	< 0.001	< 0.001	< 0.001	0.05	
Race					
Non-Hispanic white	22.8 (21.3, 24.5)	20.5 (17.5, 23.9)	22.9 (20.3, 25.6)	15.9 (13.8 (18.3)	0.84
Non-Hispanic black	6.2 (4.2, 8.9)	10.8 (7.2, 15.8)	8.6 (5.8, 12.5)	20.6 (13.0, 31.1)	< 0.001
Mexican American	20.5 (17.3, 24.3)	20.9 (16.4, 26.2)	20.9 (17.1, 25.3)	14.9 (11.7, 18.8)	0.54
Others	22.3 (15.1, 31.6)	31.0 (23.1, 40.2)	32.7 (26.6, 38.0)	6.9 (5.0, 9.6)	0.13
***P* for Race**	< 0.001	< 0.001	< 0.001	< 0.001	
Education level,					
< High school graduate	20.7 (17.5, 24.4)	21.1 (14.9, 28.9)	22.7 (19.1, 26.7)	16.6 (13.3, 20.5)	0.34
High school graduate or GED	21.3 (18.2, 24.7)	22.0 (17.6, 27.1)	21.2 (19.0, 23.5)	14.0 (11.6, 16.8)	0.47
≥ College	21.6 (19.2, 24.4)	19.4 (16.5, 22.7)	22.3 (18.9, 26.1)	14.4 (12.3, 16.8)	0.59
***P* for education**	0.88	0.22	0.57	0.50	
Family annual income					
< $25000	23.0 (20.0, 26.3)	24.5 (18.5, 31.7)	26.2 (23.5, 29.2)	15.3 (12.5, 18.6)	0.51
$25000 – $55000	19.7 (16.7, 23.2)	20.9 (17.0, 25.4)	22.1 (18.2, 26.5)	14.3 (11.6, 17.4)	0.77
> $55000	18.5 (15.1, 22.6)	15.4 (11.4, 20.4)	16.9 (13.1, 21.5)	14.9 (12.5, 17.7)	0.94
***P* for income**	0.17	0.005	< 0.001	0.80	
Watching TV time per day					
< 2 h	23.0 (17.6, 29.5)	21.1 (18.4, 24.2)	19.7 (14.8, 25.7)	14.3 (11.2, 18.1)	0.48
2-4 h	20.4 (18.8, 22.2)	21.5 (17.9, 25.7)	23.3 (21.1, 25.6)	14.5 (12.0, 17.3)	0.76
> 4 h	24.8 (19.2, 31.4)	20.5 (16.3, 25.6)	23.5 (18.9, 28.9)	13.6 (10.8, 16.9)	0.17
***P* for watching TV time**	0.42	0.68	0.08	0.95	
Physical activity level					
Moderate or below	20.3 (17.5, 23.5)	23.4 (19.2, 28.1)	22.2 (18.7, 26.1)	14.7 (11.7, 18.3)	0.35

Vigorous	15.2 (12.1, 18.8)	15.3 (11.9, 19.3)	16.4 (13.1, 20.4)	12.7 (9.8, 16.3)	0.15
***P* for physical activity level**	0.001	< 0.001	0.002	0.38	
Body mass index					
Normal or below (< 25 kg/m^2)	50.7 (45.3, 56.1)	49.7 (42.1, 57.3)	56.4 (50.4, 62.3)	41.4 (36.0, 46.9)	0.42
Overweight (25.0-29.9 kg/m^2)	5.4 (3.8, 7.8)	5.9 (4.1, 8.5)	7.2 (5.9, 8.8)	4.8 (3.4, 6.7)	0.08
Obesity (≥ 30 kg/m^2)	0.4 (0.2, 1.0)	0.3 (0.1, 1.2)	0.2 (0.1, 0.9)	--	0.30
***P* for body mass index**	<0.001	<0.001	<0.001	<0.001	

Pre-sarcopenia was defined according to dual energy X-ray absorptiometry (DXA) criteria; GED, general equivalency diploma.

[#]: *P*-trend (1999-2006): adjusted for sex, age, race, education level, family annual income, watch TV time per day, and physical activity level in logistic regression models.

Body Compositions

The average bodyweight across all participants significantly increased from 76.8 kg (95% CI: 75.6, 77.9) in 1999-2000 to 78.9 kg (95% CI: 77.4, 80.4) in 2005-2006 (*P* for trend =0.010), with an average increase of 2.11 kg (95%CI: 0.28, 3.93 kg) (**Table 3**). Correspondingly, the prevalence of obesity significantly increased from 24.3% (95%CI: 21.2%, 27.4) to 29.3% (95%CI: 25.8%, 32.7%) in the overall population (*P* for trend = 0.023), and from 20.8% (95% CI: 17.9%, 23.7%) to 27.6% (95% CI: 23.0%, 32.1%) in men (*P* for trend=0.007), but remained stable in women over time (from 28.0% to 30.9%, *P* for trend=0.229) (**Table 3 and Figure 1A**). After stratification by age (**Figure 1B**), obesity prevalence significantly increased from 25.6% to 33.8% in the 40-59 age group (*P* for trend=0.027), but remained stable in the other three age groups. Similar increased trends of obesity prevalence were observed in non-Hispanic whites (from 23.8% to 28.6%, *P* for trend =0.025) and others ethnical group (from 21.5% to 36.9%, *P* for trend =0.007), but were statistically stable in non-Hispanic blacks and Mexican Americans (**Figure 1C**). And from 1999 to 2006, SMI was significantly decreased in non-Hispanic black group, while it was significantly increased in Mexican American and others ethnical groups (**Table 3 and Figure 2A**). Meanwhile, we observed a slight increase in waist circumference (Table 3 and Figure 2B), total lean body mass (Table 3), prevalence of central obesity (Table 3), and BMD (**Table 3 and Figure 2C**).

Table 3. Trends of body weight, obesity and body compositions from 1999 to 2006 in the NHANES surveys

Characteristics	Survey cycles				*P* –trend [#]	Mean change from 1999-2000 to 2005-2006 (95% CI)
	1999-2000	2001-2002	2003-2004	2005-2006		
Weight, kg	76.8 (75.6, 77.9)	76.9 (76.1, 77.7)	78.3 (77.5, 79.0)	78.9 (77.4, 80.4)	0.010	2.11 (0.28, 3.93)
BMI, kg/m²	26.9 (26.5, 27.3)	26.8 (26.6, 27.1)	27.3 (27.0, 27.5)	27.5 (27.0, 28.0)	0.016	0.59 (-0.01, 1.20)
Overweight, % †	35.5 (32.6, 38.2)	36.7 (34.2, 39.3)	35.8 (32.9, 38.6)	34.1 (32.4, 35.9)	0.25	-1.31 (-4.45, 1.83)
Obesity, % †	24.3 (21.2, 27.4)	23.7 (21.3, 26.0)	27.6 (24.7, 30.5)	29.3 (25.8, 32.7)	0.023	4.92 (0.49, 9.36)
Waist Circumference, cm	92.6 (91.3, 93.9)	93.0 (92.4, 93.7)	94.9 (94.3, 95.5)	94.5 (93.1, 95.9)	<0.001	1.90 (0.12, 3.67)
Central obesity, % †	39.9 (35.3, 44.5)	41.5 (39.3, 43.8)	47.3 (44.5, 50.2)	45.1 (41.2, 49.1)	0.005	5.21 (-0.60, 11.0)
Total body fat percentage, %	33.0 (32.4, 33.7)	32.6 (32.3, 32.9)	33.5 (33.1, 34.0)	32.8 (32.3, 33.3)	0.766	-0.24 (-1.04, 0.56)
Total lean body mass, kg	49.3 (48.7, 49.8)	49.6 (49.1, 50.0)	49.8 (49.3, 50.3)	50.7 (50.0, 51.5)	<0.001	1.45 (0.57, 2.34)
ASM, kg *	21.7 (21.5, 22.0)	21.7 (21.4, 22.0)	21.7 (21.4, 21.9)	21.9 (21.6, 22.2)	0.986	0.16 (-0.24, 0.56)
SMI, kg/m²	7.53 (7.45, 7.61)	7.50 (7.41, 7.59	7.46 (7.38, 7.54)	7.55 (7.46, 7.64)	0.958	0.02 (-0.09, 0.14)
BMD, g/cm²	1.12 (1.11, 1.12)	1.14 (1.13, 1.14)	1.15 (1.14, 1.16)	1.17 (1.16, 1.19)	< 0.001	0.06 (0.04, 0.07)
Heart rate, beats/min	187 (186, 187)	186 (185, 187)	186 (185, 187)	--	0.15	-0.45 (-1.57, 0.66) [a]
VO_2max, ml/kg/min	40.4 (39.1, 41.8)	41.0 (40.3, 41.8)	39.4 (38.6, 40.2)	--	0.14	-1.02 (-2.52, 0.48) [a]
Low cardiovascular fitness, %	16.7 (12.6, 20.7)	12.9 (11.0, 14.8)	19.7 (16.3, 23.0)	--	0.51	3.03 (-1.99, 8.04) [a]

ASM: Appendicular skeletal muscle mass, SMI: Skeletal muscle index, BMD: Bone mineral density;

[#]: *P*-trend (1999-2006): adjusted for sex, age, race, education level, family annual income, watch TV time per day, and physical activity level.

[a]: For heart rate, VO_2max and low cardiovascular fitness, the changes were from 1999-2000 to 2003-2004.

All statistics were weighted and shown as mean (95% confidence interval) or † percentage (95% confidence interval).

--: Not available.

DISCUSSION

Using nearly 20 years of nationally representative U.S. data from NHANES, we found the overall prevalence of pre-sarcopenia remained stable between 1999 and 2006. However, stratification analyses revealed that pre-sarcopenia increased considerably among non-Hispanic blacks from 1999 to 2006. Obesity and central obesity significantly increased from 1999 to 2006. As anticipated, pre-sarcopenia and its metrics increased accordingly in young people.

Sarcopenia and obesity have common environmental risk factors, including over-nutrition, metabolic disorders, and a sedentary lifestyle.[34] Obesity can lead directly to loss of muscle mass and strength,[35] and is commonly accompanied with a reduction in physical activity and the promotion of metabolic disorders, which in turn, accelerates abnormal distribution of fat mass and initiates the process of sarcopenia.[36] Our study reveals an increasing trend in obesity prevalence across all three age groups. A significant elevation in the prevalence of pre-sarcopenia from 1999 to 2006 was observed in the young (18-39 years) age group. The peak period of skeletal muscle mass is around 20 years old which begins to decreases at around 30 years old.[37] The peak period of muscle strength lags nearly 10-years behind the peak period of muscle mass and starts to decline at around 50 years old.[38] The speed of declination of muscle strength is 2 to 5 times faster than that of muscle mass over the same period of time.[39] However, it is still unclear whether muscle mass reduction at a young age would further accelerate muscle strength loss and ageing related health issues. Observational studies reported a linearly positive association between muscle mass and strength in both middle aged and elderly people.[40-42] This indicates the higher the amount of muscle mass acquired during a young age may protect adults from the early onset of sarcopenia. Therefore, it may be beneficial for prevention and intervention strategies to pay more attention to increasing muscle mass in both young and old populations.

We did not observe significant sex differences over time in relation to pre-sarcopenia prevalence. From 1999 to 2006, pre-sarcopenia prevalence remained stable in both men and women. Previous evidence is controversial and inconsistent. Michele *et al.* compared 195 women aged 64 to 93 years old and 142 men aged 64 to 92 years old, they found a higher prevalence of sarcopenia in men than in women;[43] while in the Fifth Korea National Health and Nutrition Examination Survey, sarcopenia was more prevalent in women.[44] Women have less absolute and relative muscle mass than men[45] in biology. Besides natural differences in skeletal muscle between men and women, such as the amount of muscle mass, muscle capillary density, and muscle fiber type,[46] physical activity might be a potential cause for sex differences in sarcopenia prevalence.[47] In our study, most women had lower self-reported levels of physical activity than men. The amount of physical activity in men gradually increased, whereas it decreased in women over time. Another critical factor is age-related changes in the gonadal function and sex hormones regulating muscle mass distribution. Evidence suggested lower serum testosterone levels in elderly men contributes to muscle weakness.[48] Men experience a gradual decrease in knee extensor and handgrip strength between 20 and 80 years of age, whereas, women experience a steep decline after the age of 55 (menopausal age).[49 50] Although it is not clear whether age-related changes in the gonadal function directly regulate physical activity in humans, animals after gonadectomy can cause a dramatical decline in spontaneous physical activity.[51] Thus, sex differences might be pivotal in understanding the process of sarcopenia and aging, understanding why each sex remains “muscle healthy” throughout their lifespan could open new avenues to prevent and treat sarcopenia and the ageing process.

We also detected a considerably increased trend of pre-sarcopenia prevalence in non-Hispanic black people, while the prevalence was stable in non-Hispanic Whites, Mexican Americans and other racial groups over time. Racial differences in muscle mass have been

reported in previous studies. Evidence has shown African-Americans have significantly higher skeletal muscle/adipose tissue-free body mass ratio than other races, although the difference was very small.[52] Mahbubur and Abbey reported black women had greater levels of total and regional lean mass than White and Hispanic women, while Hispanic women had even lower values than white women after assessment of body composition of 708 healthy black, white, and Hispanic women aged 16–33 years using DXA analysis.[53] According to the NHANES III bioelectrical impedance data, the amount of fat-free mass in Mexican-Americans was lower than in non-Hispanic Blacks, which was lower than in non-Hispanic Whites.[54] The underlying mechanism of racial differences is still unclear and warrants further investigation.

This is a representative population-based study. This study firstly focused on the pre-sarcopenia among adults. Also, there are several limitations of this study. First, we only accessed muscle mass data rather than muscle strength which does not reflect muscle power and may be confounded by a third variable that was not involved in this study. Second, the prevalence of pre-sarcopenia in women may be underestimated because we used a height adjusted definition of pre-sarcopenia[55] which is potentially problematic in identifying participants with sarcopenic obesity.[56] However, if we had used the weight-adjusted definition, people classified as having sarcopenia would have had higher BMI values compared with those without sarcopenia.[57] Third, as physical activity data was self-reported, reporting bias may exist. Recent research on self-reported levels of physical activity indicated individuals in the U.S. tended to have differing perceptions of activity levels, overestimating their time spent exercising compared to Europeans.[58] Future studies should apply objective measures to muscle strength and physical activity to accurately evaluate sarcopenia prevalence.

CONCLUSIONS

Using data from the representative NHANES surveys covering nearly 20 years of data from 1999 to 2006, there was a youth tendency on prevalence of pre-sarcopenia from 1999 to 2006 among U.S. adults. Pre-sarcopenia prevalence remains stable in both men and women over time. Together with an increase in obesity and central obesity, elevations of pre-sarcopenia in non-Hispanic blacks and young people were observed. It is recommended to control body fat ratio and develop good habit of keeping resistant and moderate physical activity to prevent sarcopenia both for young and elderly people. The continued high prevalence of pre-sarcopenia and obesity is an important public health concern.

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Contributors

JL, XZ and HL designed and conducted the research; JL, XZ and HL analyzed data; JL, XZ, HL, YW and DG are responsible for the final content of the manuscript; all authors took part in writing the manuscript, read and approved the final version.

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Competing interests

None declared.

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Ethics approval

All NHANES protocols were approved by the National Center for Health Statistics Research ethics review board.

Data availability statement

The data link is https://www.cdc.gov/nchs/nhanes/index.htm.

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Figure Legends

Figure 1. Prevalence of obesity stratified by sex (A), age (B) and racial groups (C) from 1999 to 2006 in the NHANES surveys. 95% CI: 95% confidence interval. P values refer to temporal trend by logistic regression models.

Figure 2. Distribution of body compositions, including SMI (A), WC (B), BMD (C), and TPF (D) by sex, age and racial groups from 1999 to 2006. SMI: Skeletal muscle index; WC: Waist circumstance; BMD: Bone mineral density; TPF: Total percentage of body fat; 95% CI: 95% confidence interval. P values refer to temporal trend by logistic regression models.

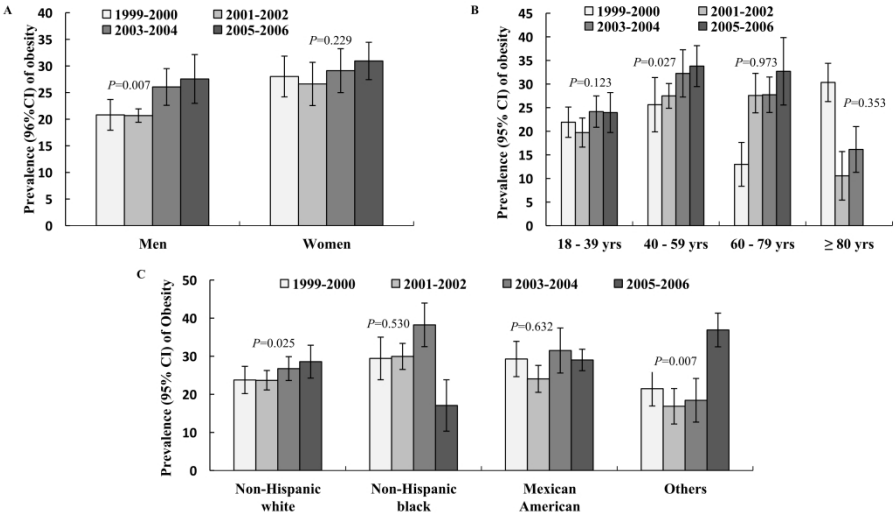

Figure 1. prevalence of obesity by gender, age and racial groups from 1999 to 2006

Figure 1. Prevalence of obesity stratified by sex (A), age (B) and racial groups (C) from 1999 to 2006 in the NHANES surveys. 95% CI: 95% confidence interval. P values refer to temporal trend by logistic regression models.

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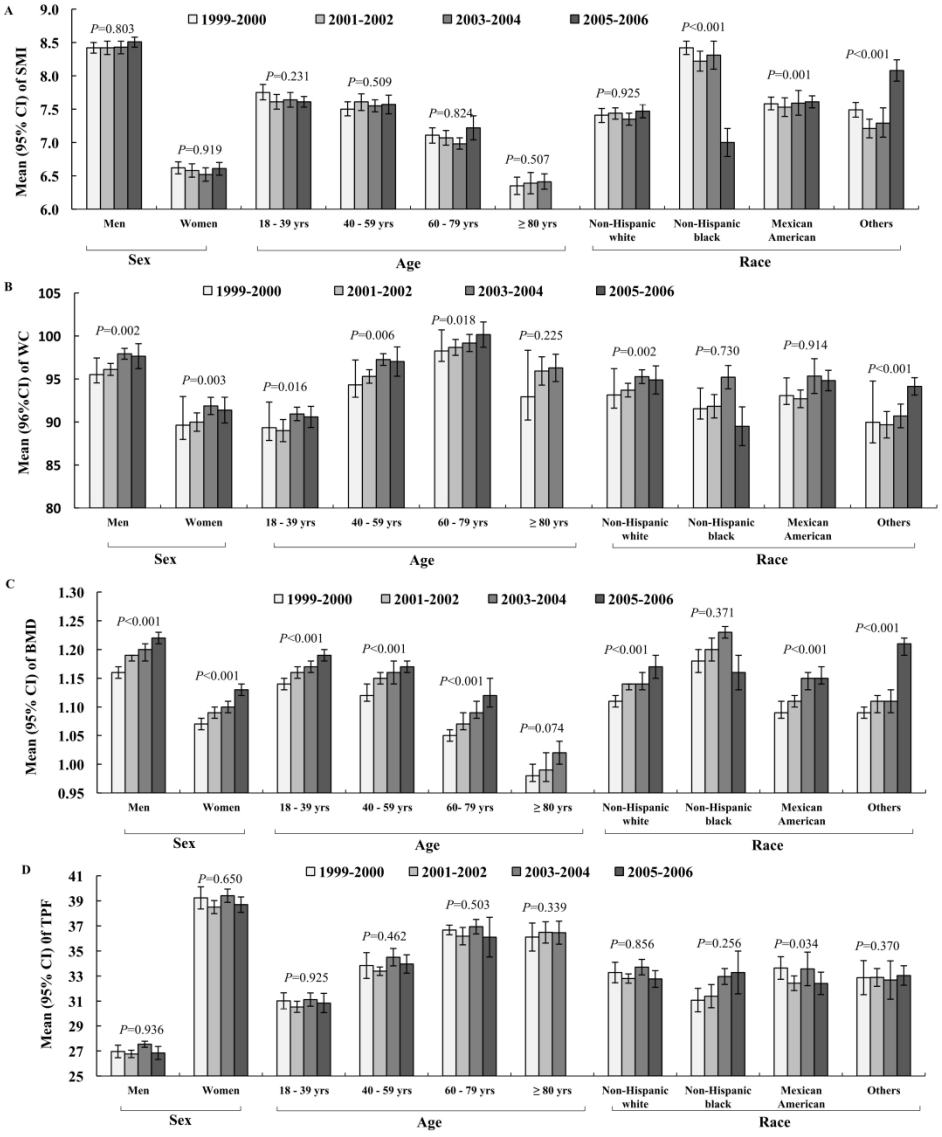

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STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	Page: 1, 3	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	Page: 5-6	Explain the scientific background and rationale for the investigation being reported
Objectives	Page: 6	State specific objectives, including any prespecified hypotheses
Methods		
Study design	Page: 6	Present key elements of study design early in the paper
Setting	Page: 6	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	Page: 6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants
Variables	Page: 6-8	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	Page: 6-8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	Page: 7-8	Describe any efforts to address potential sources of bias
Study size	Page: 6	Explain how the study size was arrived at
Quantitative variables	Page: 7-8	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	Page: 8-9	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses
Results		
Participants	Page: 9	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	Page: 9	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
Outcome data	Page:12, 15	Report numbers of outcome events or summary measures
Main results	Page: 12, 15	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	Page: 12	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity

		analyses
Discussion		
Key results	Page: 17	Summarise key results with reference to study objectives
Limitations	Page: 19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	Page:17-19	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	Page: 18	Discuss the generalisability (external validity) of the study results
Other information		
Funding	Page: 21	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Prevalence and Temporal Trends of Pre-sarcopenia Metrics and Related Body Composition Measurements from the 1999-2006 NHANES survey

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Abstract

Objective: To evaluate the prevalence and temporal trends of pre-sarcopenia and related body composition measurements.

Study design and Setting: This is an analysis study of the data from the 1999-2006 National Health and Nutrition Examination Survey (NHANES).

Methods: Pre-sarcopenia was defined according to the guidelines from the European Working Group on Sarcopenia. Logistic or linear regression models were used to evaluate the linear trend of the prevalence of pre-sarcopenia, obesity, and related body composition measurements.

Participants: A total of 29,947 participants aged 18 - 90 years from five waves of the NHANES were included in the analysis.

Outcome measures: Pre-sarcopenia was sex-specifically defined as having a skeletal mass index ≤ 7.26 kg/m^2 in men and ≤ 5.5 kg/m^2 in women. Body composition measurements, including total body fat percentage, total body fat mass, total lean body mass, appendicular skeletal muscle mass (ASM) and bone mineral density (BMD), were obtained by dual energy X-ray absorptiometry.

Results: The overall prevalence of pre-sarcopenia ranged from 16.4% in 1999-2000 to 14.8% in 2005-2006 (P for trend=0.78). Pre-sarcopenia was stable in both males (*P* for trend=0.36) and females (P for trend=0.20). The pre-sarcopenia prevalence was significantly elevated among the 18- to 39-year-old age group (from 11.3% to 14.1%, P for trend = 0.04) and among non-Hispanic blacks (from 6.2% to 20.6%, *P* for trend < 0.001). Adults aged ≥ 80 years old had the highest prevalence.

Conclusions: The prevalence of pre-sarcopenia increased among young individuals over time. Non-Hispanic blacks also demonstrated an increasing trend in the prevalence over time.

Keywords: Pre-sarcopenia Metrics; Body Composition; Temporal Trends.

Strengths and limitations of this study

- We used the data from the nationally representative population-based surveys of the NHANES (1999-2006).
- Body composition measurements were obtained by the gold standard dual energy X-ray absorptiometry.
- Appendicular skeletal muscle mass rather than muscle strength and physical performance was assessed.
- The prevalence of pre-sarcopenia in women may be underestimated when using a height-adjusted definition of pre-sarcopenia.
- Reporting bias may exist due to self-reported physical activity data.

INTRODUCTION

According to the 2010 European Working Group on Sarcopenia in Older People (EWGSOP), sarcopenia is defined as a cluster of geriatric conditions characterized by progressive and generalized loss of skeletal muscle mass and strength with a high risk of adverse outcomes, including poor quality of life, physical disability, and even death. [1] The prevalence of pre-sarcopenia (5.9%) and sarcopenia (4.4%) among adults aged 45 years and older is high in the Netherlands [2]. It has been conservatively estimated that sarcopenia affects more than 50 million people around the world and will increase by more than 200 million over the next 40 years. [3]

Currently, there are a variety of definitions for sarcopenia, none of which have been agreed upon, and the prevalence of the disease is highly dependent on the diagnostic criteria used. Among the three components of sarcopenia defined in the EWGSOP, muscle mass, muscle strength, and performance, muscle mass plays a critical role in the progression of sarcopenia, and low muscle mass has been identified as pre-sarcopenia. Sarcopenia, especially in the context low skeletal muscle mass, is mainly caused by ageing, decreased participation in physical activities, [4] malnutrition, [5 6] and endocrine and metabolic disorders. [7] These factors directly contribute to the loss of muscle mass, [8] influencing muscle strength and performance and leading to a lower metabolic rate and reduced physical activity, which often causes fat gain. The gained fat could lead to a further loss of muscle mass and strength via cytokine protein catabolism [9] and insulin resistance. [10] Thus, sarcopenia and its effects can be part of a spiralling process of declining health.

Sarcopenic obesity, defined as a loss in body lean mass but preservation or even an increase in body fat mass, can have serious health implications. Recent data has indicated that obesity affects more people of younger age due to physical inactivity. [11] Therefore, it is reasonable to hypothesize that the prevalence of pre-sarcopenia has increased accordingly.

Currently, there is a lack of evidence to support this statement. Numerous studies have reported that sarcopenia/low muscle mass is related to frailty, [12] inflammation, [13 14] liver fibrosis, [15 16] cirrhosis, [17 18] systemic sclerosis, [19] cancer, [20-22] chronic obstructive pulmonary disease, [23] cardiovascular disease (CVD), [24 25] and mortality, [26] all of which place considerable health and economic burdens on public health care services. Thus, it is important to depict the prevalence and temporal trends of pre-sarcopenia and related body composition measurements over time in relation to sex, age, and race to better inform public health policy and prevention strategies.

In this study, we estimated the population-based prevalence and temporal trends of pre-sarcopenia metrics and related body composition measurements among adults in the United States (U.S.) from 1999 to 2006 by using data from the National Health and Nutrition Examination Survey (NHANES).

METHODS

Study design and participants

The NHANES is a nationally representative cross-sectional survey among non-institutionalized civilians in the U.S. [27] This analytical study involved participants aged 18 years and older from the NHANES cohort surveyed across four consecutive cycles: 1999-2000 (*n*=3,559), 2001-2002 (*n*=4,047), 2003-2004 (*n*=3,771), and 2005-2006 (*n*=3,071). All NHANES protocols were approved by the National Centre for Health Statistics Research ethics review board. All participants provided written informed consent.

Body component measurements and pre-sarcopenia

Physical examinations were conducted in mobile examination centres. Weight in kilograms, height in centimetres, and waist circumference (WC) in centimetres were measured using standardized techniques and equipment. Body mass index (BMI) was calculated as

weight in kilograms divided by the square of the height in metres. Overweight was defined as a BMI between 25.0-29.9 and obesity as a BMI of 30.0 or higher. [28] Central obesity was defined as having a WC of > 102 cm for males and > 88 cm for females. [29] Total body fat percentage, total body fat mass, total lean body mass, appendicular skeletal muscle mass (ASM) and bone mineral density (BMD) were measured using dual energy X-ray absorptiometry (DXA) in the four surveys from 1999 to 2006. The total appendicular skeletal muscle mass index (TASM) was calculated as the ASM divided by the height squared (kg/m^2). Pre-sarcopenia was sex-specifically defined as having a TASM $\leq$ 7.26 kg/m^2 in men and $\leq$ 5.5 kg/m^2 in women. [30]

Physical activity and social-demographic factors

Participants' sex, age, race, education level, annual household income, time spent watching television per day, and level of physical activity were collected by household interviews. Age was grouped into three categories: 18 to 39 years old, 40 to 59 years old, and 60 years or older. Race was classified as non-Hispanic white, non-Hispanic black, Mexican American, and others. Educational level was categorized into < high school graduate, high school graduate/general equivalency diploma, or ≥ college. Time spent watching TV per day was grouped into < 2 h, 2–4 h, or > 4 h. Annual household income was grouped into < $25000, $25000 to $55000, or > $55000. Physical activity was grouped into two levels: moderate/below or vigorous.

Statistical analyses

Participants' characteristics, including sex, age, race, education level, annual household income, time spent watching TV per day and level of physical activity, are shown as unweighted frequencies and weighted percentages with 95% confidence intervals. Weighted means and corresponding 95% confidence intervals of body weight, BMI and obesity, WC

and central obesity, total body fat percentage, total lean body mass, ASM, TASM, and BMD were calculated, and mean changes with 95% confidence intervals (CIs) of all these variables from 1999-2000 to 2005-2006 were calculated.

The age- and sex-adjusted prevalence of pre-sarcopenia was calculated for the four survey cycles from 1999-2000 to 2005-2006 for the overall sample and the sex, age, race, education level, annual household income, time spent watching TV per day, and physical activity level subgroups. The temporal trends of pre-sarcopenia prevalence, obesity and different body composition measurements, including TASM, WC, BMD, and TPF, for the overall sample and within the subgroups were assessed by survey-weighted linear (for continuous outcomes) or logistic (for binary outcomes) regression models with survey year as a continuous (ordered categorical) independent variable after adjustment for sex, age, race, education level, annual household income, time spent watching TV per day, and physical activity level [31 32].

Sampling weights were used to account for unequal probabilities of selection and nonresponses for all analyses, thereby providing estimates representative of the non-institutionalized civilian U.S. population. All statistical analyses were performed using SAS for Windows version 9.4 (SAS Institute, Cary, NC, USA). A two-sided $P < 0.05$ was considered statistically significant.

Patient and public involvement

There was no patient or public involvement in this study.

RESULTS

A total of 14,448 participants were included in this study, with 3,559 from 1999-2000, 4,047 from 2001-2002, 3,771 from 2003-2004, and 3,071 from 2005-2006 (**Table 1**). The distributions of the participants' characteristics across the four survey cycles were comparable.

In 1999-2000, 49.6% of the participants were women, 19.5% were 60 years or older, and 71.7% were non-Hispanic white. The proportion of patients with a vigorous physical activity level showed a significantly decreasing trend from 1999 to 2006 (P <0.001).

174 **Table 1. Participants' characteristics (weighted) from the NHANES surveys, 1999-2006**

Characteristics	No. weighted (%)			
	1999-2000 (*n* = 3559)	2001-2002 (*n* = 4047)	2003-2004 (*n* = 3771)	2005-2006 (*n* = 3071)
Sex				
Men	1829 (50.4) [48.4, 52.5]	2106 (50.0) [48.6, 51.3]	1932 (49.5) [47.5, 51.6]	1574 (49.7) [48.0, 51.5]
Women	1730 (49.6) [47.5, 51.7]	1941 (50.0) [48.7, 51.4]	1839 (50.5) [48.4, 52.6]	1497 (50.3) [48.5, 52.0]
Age group, mean (SD) [95% CI]	43.3 (0.5) [42.1, 44.4]	43.6 (0.5) [42.5, 44.7]	44.2 (0.6) [43.0, 45.4]	41.4 (0.4) [40.5, 42.4]
18 – 39 yrs	1493 (47.3) [44.7 49.9]	1704 (44.0) [39.9, 48.1]	1592 (42.4) [38.5, 46.3]	1540 (44.9) [41.9, 47.8]
40 – 59 yrs	964 (33.2) [31.1 35.4]	1217 (38.2) [34.8, 41.7]	1015 (38.0) [34.7, 41.3]	1067 (43.8) [41.6, 46.4]
60– 79 yrs	913 (17.1) [14.7, 19.4]	887 (15.2) [13.8, 16.7]	915 (16.7) [15.1, 18.3]	464 (11.3) [9.3, 13.3]
≥ 80 yrs	189 (2.4) [1.9, 2.8]	239 (2.6) [2.1, 2.0]	249 (2.9) [2.2. 3.5]	--
Race				
Non-Hispanic white	1513 (71.7) [65.5, 77.9]	2014 (72.4) [67.5, 77.4]	1915 (73.2) [65.9, 80.5]	1321 (71.1) [65.1, 77.1]
Non-Hispanic black	642 (9.5) [6.25, 12.8]	785 (10.1) [6.9, 13.2]	796 (10.5) [6.6, 14.3]	128 (5.1) [3.4, 6.9]
Mexican American	1082 (6.6) [3.6, 9.5]	960 (7.7) [5.7, 9.7]	799 (7.7) [3.7, 11.7]	746 (8.90) [6.3, 11.5]
Others	322 (12.2) [5.8, 18.6]	288 (9.8) [5.8, 13.9]	261 (8.7) [6.3, 11.0]	876 (14.8) [10.9, 18.8]
Education level				
< High school graduate	1408 (23.6) [20.4, 26.7]	1300 (19.2) [17.0, 21.4]	1114 (17.8) [15.0, 20.5]	662 (15.5) [11.9, 19.2]
High school graduate/GED	840 (26.4) [22.4, 30.4]	980 (25.5) [23.3, 27.7]	978 (26.9) [24.7, 29.1]	618 (24.5) [22.1, 26.9]
≥ College	1302 (50.0) [45.8, 54.2]	1763 (55.3) [51.9, 58.7]	1675 (55.3) [52.0, 58.7]	1363 (60.0) [55.2, 64.9]
Annual household income				
< $25000	1452 (36.7) [29.6, 43.8]	1479 (29.7) [27.1, 32.3]	1518 (30.6) [26.7, 34.3]	920 (20.9) [17.6, 24.2]
$25000 – $55000	902 (30.8) [26.8, 34.8]	1163 (30.9) [27.5, 34.3]	1081 (32.0) [27.5, 36.5]	934 (30.6) [27.2, 34.1]
> $55000	731 (32.5) [26.7, 38.2]	1133 (39.4) [35.6, 43.1]	958 (37.4) [32.2, 42.7]	1097 (48.5) [43.6, 53.5]
Time spent watching TV per day, mean (SD) [95% CI]	2.34 (0.03) [2.28, 2.41]	2.31 (0.04) [2.24, 2.39]	2.16 (0.05) [2.06, 2.27]	2.07 (0.05) [1.97, 2.17]
< 2 h	621 (19.5) [17.7, 21.6]	606 (19.8) [17.9, 21.6]	634 (22.0) [19.3, 24.8]	545 (22.5) [20.8, 24.2]
2-4 h	2072 (68.3) [66.7, 69.9]	2215 (63.2) [61.4, 65.2]	2040 (64.7) [61.5, 67.9]	1674 (66.8) [65.0, 68.5]
> 4 h	428 (12.2) [10.7, 13.8]	674 (17.0) [15.6, 18.4]	542 (13.3) [10.7, 15.9]	354 (10.7) [8.49, 13.0]
Physical activity level				
Moderate or below	888 (44.0) [40.1, 47.8]	1236 (51.0) [47.0, 55.0]	1451 (61.5) [58.4, 64.6]	1066 (54.0) [51.0, 57.0]
Vigorous	1013 (56.0) [52.2, 59.9]	1253 (49.0) [45.0, 53.0]	963 (38.5) [35.5, 41.6]	1027 (46.0) [43.1, 49.0]
Body mass index				
Normal or below (< 25 kg/m^2)	1351 (40.1) [36.3, 43.9]	1617 (39.6) [38.0, 41.2]	1389 (36.6) [34.6, 38.6]	1089 (36.6) [33.1, 40.2]

Overweight (25.0-29.9 kg/m²)	1289 (35.5) [32.7, 38.3]	1494 (36.7) [34.2, 39.3]	1348 (35.8) [32.9, 38.6]	1054 (34.1) [32.4, 35.9]
Obesity (≥ 30 kg/m²)	914 (24.4) [21.3, 27.5]	936 (23.7) [21.3, 26.0]	1034 (27.6) [24.7, 30.5]	928 (29.3) [25.8, 32.7]

--: Not available.

Prevalence and temporal trends of pre-sarcopenia from 1999 to 2006

The overall age- and sex-adjusted prevalence of pre-sarcopenia ranged from 16.4% (95% CI: 15.3%, 17.6%) in 1999-2000 to 14.8% (95% CI: 13.0%, 16.8%) in 2005-2006 (*P* for trend = 0.78) (**Table 2)**.

The age-adjusted prevalence of pre-sarcopenia in men was 22.7% (95% CI: 20.3%, 25.2%) in 1999-2000 and 12.3% (95% CI: 10.6%, 14.3%) in 2005-2006 (*P* for trend = 0.36), while in women, the prevalence was 20.0% in 1999-2000 and 17.7% in 2005-2006 (*P* for trend = 0.20). The prevalence of pre-sarcopenia in women was significantly higher than that in men in 2005-2006 (17.7% for women vs. 12.3% for men; $P < 0.001$). There were also racial differences in pre-sarcopenia prevalence as well as temporal trends. The prevalence significantly increased from 6.2% in 1999-2000 to 20.6% in 2005-2006 among non-Hispanic blacks (*P* for trend < 0.001) but remained stable among non-Hispanic whites (*P* for trend = 0.84) and Mexican Americans (*P* for trend = 0.54) from 1999 to 2006. Compared to those in the other age groups, participants aged ≥ 80 years and 60 – 79 years had a significantly higher prevalence of pre-sarcopenia in the four survey cycles from 1999-2006. In three of the survey cycles (1999-2000, 2001-2002, and 2003-2004), compared to those who reported moderate/low physical activity levels, participants who reported vigorous physical activity levels were more likely to have a lower prevalence of pre-sarcopenia (*P* values < 0.01). In addition, participants with higher annual household incomes had a lower prevalence of pre-sarcopenia in the 2001-2002 and 2003-2004 survey cycles. In all four survey cycles, participants with BMI < 25 kg/m^2 had a relatively higher prevalence of pre-sarcopenia than overweight and obese participants.

Table 2. Prevalence (95% CIs) and temporal trends of pre-sarcopenia in the NHANES surveys from 1999 to 2006

Characteristics	1999-2000 (n=3550)	2001-2002 (n=3987)	2003-2004 (n=3745)	2005-2006 (n=3062)	*P*-value for trend #
Overall	16.4 (15.3, 17.6)	16.4 (14.0, 19.1)	17.9 (16.2, 19.7)	14.8 (13.0, 16.8)	0.78
Sex					
Men	22.7 (20.3, 25.2)	19.7 (15.9, 24.2)	21.2 (18.8, 23.7)	12.3 (10.6, 14.3)	0.36
Women	20.0 (17.9, 22.3)	21.4 (17.7, 25.5)	23.0 (19.8, 26.6)	17.7 (14.9, 20.9)	0.20
***P* for sex**	0.45	0.23	0.23	< 0.001	
Age group					
18 – 39 yrs	11.3 (9.1, 14.0)	13.5 (10.6, 17.0)	14.9 (12.8, 17.3)	14.1 (11.8, 16.8)	0.04
40 – 59 yrs	15.1 (12.9, 17.5)	12.1 (9.9, 14.7)	14.2 (11.6, 17.2)	12.9 (11.0, 15.2)	0.25
60 – 79 yrs	22.3 (19.0, 26.1)	23.7 (18.7, 29.6)	23.6 (20.3, 27.2)	17.7 (14.4, 21.5)	0.38
≥ 80 yrs	45.1 (38.7, 51.6)	40.1 (31.8, 49.0)	42.0 (36.2, 48.0)	--	0.64
***P* for age group**	< 0.001	< 0.001	< 0.001	0.05	
Race					
Non-Hispanic white	22.8 (21.3, 24.5)	20.5 (17.5, 23.9)	22.9 (20.3, 25.6)	15.9 (13.8 (18.3)	0.84
Non-Hispanic black	6.2 (4.2, 8.9)	10.8 (7.2, 15.8)	8.6 (5.8, 12.5)	20.6 (13.0, 31.1)	< 0.001
Mexican American	20.5 (17.3, 24.3)	20.9 (16.4, 26.2)	20.9 (17.1, 25.3)	14.9 (11.7, 18.8)	0.54
Others	22.3 (15.1, 31.6)	31.0 (23.1, 40.2)	32.7 (26.6, 38.0)	6.9 (5.0, 9.6)	0.13
***P* for Race**	< 0.001	< 0.001	< 0.001	< 0.001	
Education level,					
< High school graduate	20.7 (17.5, 24.4)	21.1 (14.9, 28.9)	22.7 (19.1, 26.7)	16.6 (13.3, 20.5)	0.34
High school graduate or GED	21.3 (18.2, 24.7)	22.0 (17.6, 27.1)	21.2 (19.0, 23.5)	14.0 (11.6, 16.8)	0.47
≥ College	21.6 (19.2, 24.4)	19.4 (16.5, 22.7)	22.3 (18.9, 26.1)	14.4 (12.3, 16.8)	0.59
***P* for education**	0.88	0.22	0.57	0.50	
Annual household income					
< $25000	23.0 (20.0, 26.3)	24.5 (18.5, 31.7)	26.2 (23.5, 29.2)	15.3 (12.5, 18.6)	0.51
$25000 – $55000	19.7 (16.7, 23.2)	20.9 (17.0, 25.4)	22.1 (18.2, 26.5)	14.3 (11.6, 17.4)	0.77
> $55000	18.5 (15.1, 22.6)	15.4 (11.4, 20.4)	16.9 (13.1, 21.5)	14.9 (12.5, 17.7)	0.94
***P* for income**	0.17	0.005	< 0.001	0.80	
Time spent watching TV per day					
< 2 h	23.0 (17.6, 29.5)	21.1 (18.4, 24.2)	19.7 (14.8, 25.7)	14.3 (11.2, 18.1)	0.48
2-4 h	20.4 (18.8, 22.2)	21.5 (17.9, 25.7)	23.3 (21.1, 25.6)	14.5 (12.0, 17.3)	0.76
> 4 h	24.8 (19.2, 31.4)	20.5 (16.3, 25.6)	23.5 (18.9, 28.9)	13.6 (10.8, 16.9)	0.17
***P* for time spent watching TV**	0.42	0.68	0.08	0.95	
Physical activity level					

Moderate or below	20.3 (17.5, 23.5)	23.4 (19.2, 28.1)	22.2 (18.7, 26.1)	14.7 (11.7, 18.3)	0.35
Vigorous	15.2 (12.1, 18.8)	15.3 (11.9, 19.3)	16.4 (13.1, 20.4)	12.7 (9.8, 16.3)	0.15
***P* for physical activity level**	0.001	< 0.001	0.002	0.38	
Body mass index					
Normal or below (< 25 kg/m^2)	50.7 (45.3, 56.1)	49.7 (42.1, 57.3)	56.4 (50.4, 62.3)	41.4 (36.0, 46.9)	0.42
Overweight (25.0-29.9 kg/m^2)	5.4 (3.8, 7.8)	5.9 (4.1, 8.5)	7.2 (5.9, 8.8)	4.8 (3.4, 6.7)	0.08
Obesity (≥ 30 kg/m^2)	0.4 (0.2, 1.0)	0.3 (0.1, 1.2)	0.2 (0.1, 0.9)	--	0.30
***P* for body mass index**	<0.001	<0.001	<0.001	<0.001	

--: Not available.

Pre-sarcopenia was defined according to dual energy X-ray absorptiometry (DXA) criteria: GED, general equivalency diploma.

[#]: *P*-value for trend (1999-2006) was calculated by using logistic regression models adjusted for sex, age, race, education level, annual household income, time spent watching TV per day, and physical activity level.

P-values for the differences between groups in each survey cycle were obtained by the chi-squared test.

Body Composition Measurements

The average body weight across all participants significantly increased from 76.8 kg (95% CI: 75.6, 77.9) in 1999-2000 to 78.9 kg (95% CI: 77.4, 80.4) in 2005-2006 (*P* for trend =0.010), with an average increase of 2.11 kg (95% CI: 0.28, 3.93 kg) (**Table 3**). Correspondingly, the prevalence of obesity significantly increased from 24.3% (95% CI: 21.2%, 27.4%) to 29.3% (95% CI: 25.8%, 32.7%) in the overall population (*P* for trend = 0.023) and from 20.8% (95% CI: 17.9%, 23.7%) to 27.6% (95% CI: 23.0%, 32.1%) in men (*P* for trend=0.007) but remained stable in women (from 28.0% to 30.9%, *P* for trend=0.229) over time (**Table 3 and Figure 1A**). After stratification by age (**Figure 1B**), the prevalence of obesity significantly increased from 25.6% to 33.8% in the 40-59 age group (*P* for trend=0.027) but remained stable in the other three age groups. Similar increasing trends of obesity prevalence were observed in non-Hispanic whites (from 23.8% to 28.6%, *P* for trend =0.025) but were statistically stable in non-Hispanic blacks and Mexican Americans (**Figure 1C**). From 1999 to 2006, the TASM significantly decreased in the non-Hispanic black group but significantly increased in the Mexican American and other ethnic groups (**Table 3 and Figure 2A**). Meanwhile, we observed a slight increase in waist circumference (Table 3 and Figure 2B), total lean body mass (Table 3), prevalence of central obesity (Table 3), and BMD (**Table 3 and Figure 2C**).

Table 3. Trends in body weight, obesity and other body composition measurements from 1999 to 2006 in the NHANES surveys

Characteristics	Survey cycles				*P* -value for trend #	Mean change from 1999-2000 to 2005-2006 (95% CI)
	1999-2000	2001-2002	2003-2004	2005-2006		
Weight, kg	76.8 (75.6, 77.9)	76.9 (76.1, 77.7)	78.3 (77.5, 79.0)	78.9 (77.4, 80.4)	0.010	2.11 (0.28, 3.93)
BMI, kg/m²	26.9 (26.5, 27.3)	26.8 (26.6, 27.1)	27.3 (27.0, 27.5)	27.5 (27.0, 28.0)	0.016	0.59 (-0.01, 1.20)
Overweight, % †	35.5 (32.6, 38.2)	36.7 (34.2, 39.3)	35.8 (32.9, 38.6)	34.1 (32.4, 35.9)	0.25	-1.31 (-4.45, 1.83)
Obesity, % †	24.3 (21.2, 27.4)	23.7 (21.3, 26.0)	27.6 (24.7, 30.5)	29.3 (25.8, 32.7)	0.023	4.92 (0.49, 9.36)
Waist Circumference, cm	92.6 (91.3, 93.9)	93.0 (92.4, 93.7)	94.9 (94.3, 95.5)	94.5 (93.1, 95.9)	<0.001	1.90 (0.12, 3.67)
Central obesity, % †	39.9 (35.3, 44.5)	41.5 (39.3, 43.8)	47.3 (44.5, 50.2)	45.1 (41.2, 49.1)	0.005	5.21 (-0.60, 11.0)
Total body fat percentage, %	33.0 (32.4, 33.7)	32.6 (32.3, 32.9)	33.5 (33.1, 34.0)	32.8 (32.3, 33.3)	0.766	-0.24 (-1.04, 0.56)
Total lean body mass, kg	49.3 (48.7, 49.8)	49.6 (49.1, 50.0)	49.8 (49.3, 50.3)	50.7 (50.0, 51.5)	<0.001	1.45 (0.57, 2.34)
ASM, kg *	21.7 (21.5, 22.0)	21.7 (21.4, 22.0)	21.7 (21.4, 21.9)	21.9 (21.6, 22.2)	0.986	0.16 (-0.24, 0.56)
SMI, kg/m²	7.53 (7.45, 7.61)	7.50 (7.41, 7.59	7.46 (7.38, 7.54)	7.55 (7.46, 7.64)	0.958	0.02 (-0.09, 0.14)
BMD, g/cm²	1.12 (1.11, 1.12)	1.14 (1.13, 1.14)	1.15 (1.14, 1.16)	1.17 (1.16, 1.19)	< 0.001	0.06 (0.04, 0.07)

ASM: Appendicular skeletal muscle mass, TASM: Total appendicular skeletal muscle index, BMD: Bone mineral density;

#: *P*-value for trend (1999-2006) was adjusted for sex, age, race, education level, annual household income, time spent watching TV per day, and physical activity level.

All statistics were weighted and shown as the means (95% confidence interval) or † percentages (95% confidence intervals).

DISCUSSION

In this large-scale study that analysed nationally representative data from U.S. respondents to the NHANES, we found that the overall prevalence of pre-sarcopenia remained stable, while there was a substantial increase in the prevalence for the non-Hispanic black and young age groups from 1999 to 2006. Hence, our hypothesis regarding an increasing trend in the pre-sarcopenia prevalence over time was not fully supported by the findings. Our results indicate that certain subpopulations might be more vulnerable to pre-sarcopenia than the overall population. Indeed, we found that individuals who were older or under/normal weight had a considerably higher prevalence of pre-sarcopenia.

Our study found an increasing trend in the prevalence of obesity and central obesity from 1999 to 2006 among the overall population. Previous studies reported that obesity can lead to loss of muscle mass and strength [33] and is commonly accompanied by a reduction in physical activity and deterioration of metabolic disorders, which in turn accelerates the abnormal distribution of fat mass and initiates the process of sarcopenia. [34] In contrast, it is interesting that the prevalence of pre-sarcopenia was considerably higher in under/normal weight adults than in obese adults in our study. The contradictory findings might be explained by the fact that our study only measured skeletal muscle mass, but the muscle mass of under/normal weight individuals might be relatively lower than that of overweight/obese individuals. In addition, our study focused on pre-sarcopenia rather than sarcopenia, which is defined as the presence of both low muscle mass and low muscle function (strength or physical performance).

A previous study reported that skeletal muscle mass begins to decrease at approximately 30 – 39 years old. [35] Accordingly, we found a relatively higher prevalence of pre-sarcopenia in the older age groups than in the 18-39 age group. However, it is still unclear whether muscle mass reduction would further accelerate muscle strength loss and ageing-

related health issues. Observational studies have reported a linearly positive association between muscle mass and strength in both middle-aged and elderly people. [36-38] This indicates that the amount of muscle mass acquired during youth may protect adults from the early onset of sarcopenia. Therefore, it may be beneficial to pay more attention to increasing muscle mass in both young and old populations. The peak period of muscle strength lags nearly 10 years behind the peak period of muscle mass and starts to decline at approximately 50 years of age. [39] The speed of muscle strength decline is 2 to 5 times faster than that of muscle mass over the same period.[40]

We found that the prevalence of pre-sarcopenia was stable in both genders from 1999 to 2006. It was also found that women had a higher prevalence of pre-sarcopenia than men in 2005-2006. This might be caused by a more rapid decrease in the prevalence of pre-sarcopenia among men than women. Previous evidence, however, is inconsistent. For instance, the study of Michele *et al.* found a higher prevalence of sarcopenia in men than in women who were aged 64 to 93 years, [41] while the findings in the Fifth Korea National Health and Nutrition Examination Survey showed that sarcopenia was more prevalent in women. [42] Women have less absolute and relative muscle mass than men. [43] In addition, given the natural differences in skeletal muscle between men and women, such as the amount of muscle mass, muscle capillary density, and muscle fibre type, [44] physical activity might be a potential cause for sex differences in the prevalence of sarcopenia. [45] In our study, most women had lower self-reported levels of physical activity than men. Vigorous physical activity in men gradually increased, whereas it decreased in women over time. Another critical factor is age-related changes in gonadal function and sex hormones regulating muscle mass distribution. Evidence suggests that lower serum testosterone levels in elderly men contribute to muscle weakness. [46] Men experience a gradual decrease in knee extensor and handgrip strength between 20 and 80 years of age, whereas women experience a steep decline

after the age of 55 (menopausal age). [47 48] Although it is not clear whether age-related changes in gonadal function directly regulate physical activity in humans, gonadectomy has been shown to cause a dramatic decline in spontaneous physical activity in animals. [49] Thus, sex differences might be pivotal in understanding the process of sarcopenia and ageing, and understanding why each sex remains "muscle healthy" throughout their lifespan could open new avenues to prevent sarcopenia and the ageing process.

We also detected a considerably increased trend of pre-sarcopenia prevalence in non-Hispanic black people, while the prevalence was stable in non-Hispanic whites and Mexican Americans over time. Racial differences in muscle mass have been reported in previous studies. Evidence has shown that African Americans have a significantly higher skeletal muscle/adipose tissue-free body mass ratio than other races, although the difference was very small. [50] Mahbubur and Abbey reported that black women had greater levels of total and regional lean mass than white and Hispanic women and that Hispanic women had even lower values than white women in an assessment of the body composition of 708 healthy black, white, and Hispanic women aged 16–33 years using DXA analysis. [51] According to the NHANES III bioelectrical impedance data, the amount of fat-free mass in Mexican Americans was lower than that in non-Hispanic Blacks, which was in turn lower than that in non-Hispanic Whites. [52] The underlying mechanism of these racial differences is still unclear and warrants further investigation.

This is a representative population-based study. This is the first study that focused on pre-sarcopenia among adults. However, there are several limitations in this study. First, we only assessed muscle mass data rather than muscle strength, which does not reflect muscle power and may be confounded by a third variable that was not involved in this study. Second, the prevalence of pre-sarcopenia in women may be underestimated because we used a height-adjusted definition of the condition, [53] which is potentially problematic in identifying

participants with sarcopenic obesity. [54] However, if we had used the weight-adjusted definition, people classified as having pre-sarcopenia would have had higher BMI values compared with those without sarcopenia. [55] Third, as physical activity data were self-reported, reporting bias may exist. Recent research on self-reported levels of physical activity indicated that individuals in the U.S. tended to have differing perceptions of activity levels and that compared to Europeans, U.S. individuals overestimate their time spent exercising. [56] Future studies should apply objective measures to determine muscle strength and physical activity to accurately evaluate sarcopenia prevalence.

CONCLUSIONS

The overall prevalence of pre-sarcopenia was stable in both men and women from 1999-2006 among U.S. adults, while there is a slight increase in the prevalence of pre-sarcopenia from 1999 to 2006 among U.S. young adults. Adults who were elderly or under/normal weight are at high-risk of pre-sarcopenia. Meanwhile, we found a significant increased trend of obesity, central obesity, and pre-sarcopenia in non-Hispanic blacks and young adults. It suggests that the high prevalence of pre-sarcopenia and obesity is an important public health concern. It might be helpful to maintain resistant and at least moderate physical activity for the prevention of sarcopenia and obesity in U.S. adults.

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Contributors

JBL, XZ and HJL designed and conducted the research; JBL, XZ and HJL analysed the data; JBL, XZ, HJL, YWW and DTG were responsible for the final content of the manuscript; all authors took part in writing the manuscript and read and approved the final version.

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Competing interests

None declared.

Patient consent for publication

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Ethics approval

All NHANES protocols were approved by the National Centre for Health Statistics Research ethics review board.

Data availability statement

The data link is https://www.cdc.gov/nchs/nhanes/index.htm.

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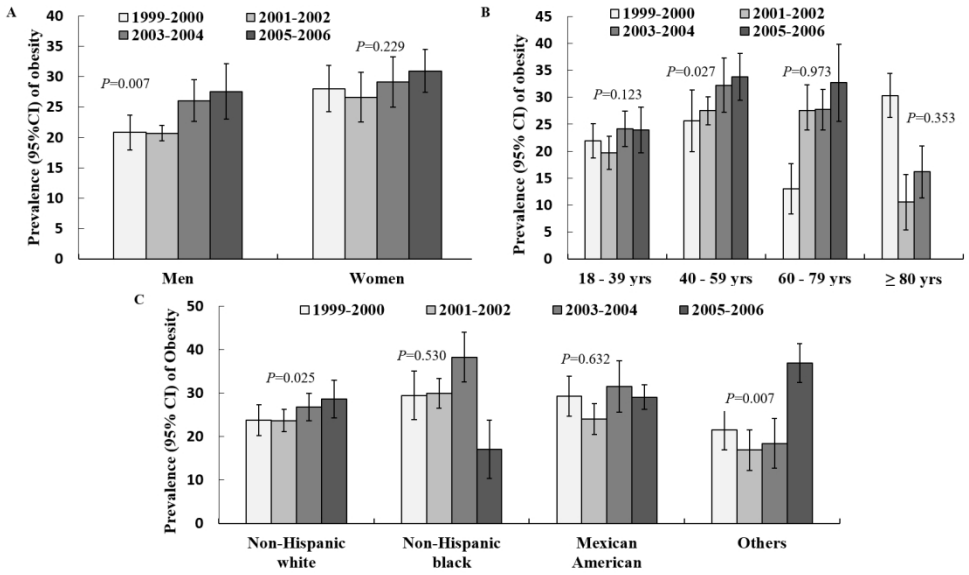
Figure Legends

Figure 1. Prevalence of obesity stratified by sex (A), age (B) and racial group (C) from 1999 to 2006 in the NHANES surveys. 95% CI: 95% confidence interval. P values refer to temporal trends obtained by logistic regression models after adjusting for sex, age, race, education level, annual household income, time spent watching TV per day, and physical activity level.

Figure 2. Distribution of body composition measurements, including SMI (A), WC (B), BMD (C), and TPF (D), by sex, age and racial group from 1999 to 2006. SMI: Skeletal muscle index; WC: Waist circumstance; BMD: Bone mineral density; TPF: Total percentage of body fat; 95% CI: 95% confidence interval. P values refer to temporal trends obtained by logistic regression models after adjusting for sex, age, race, education level, annual household income, time spent watching TV per day, and physical activity level.



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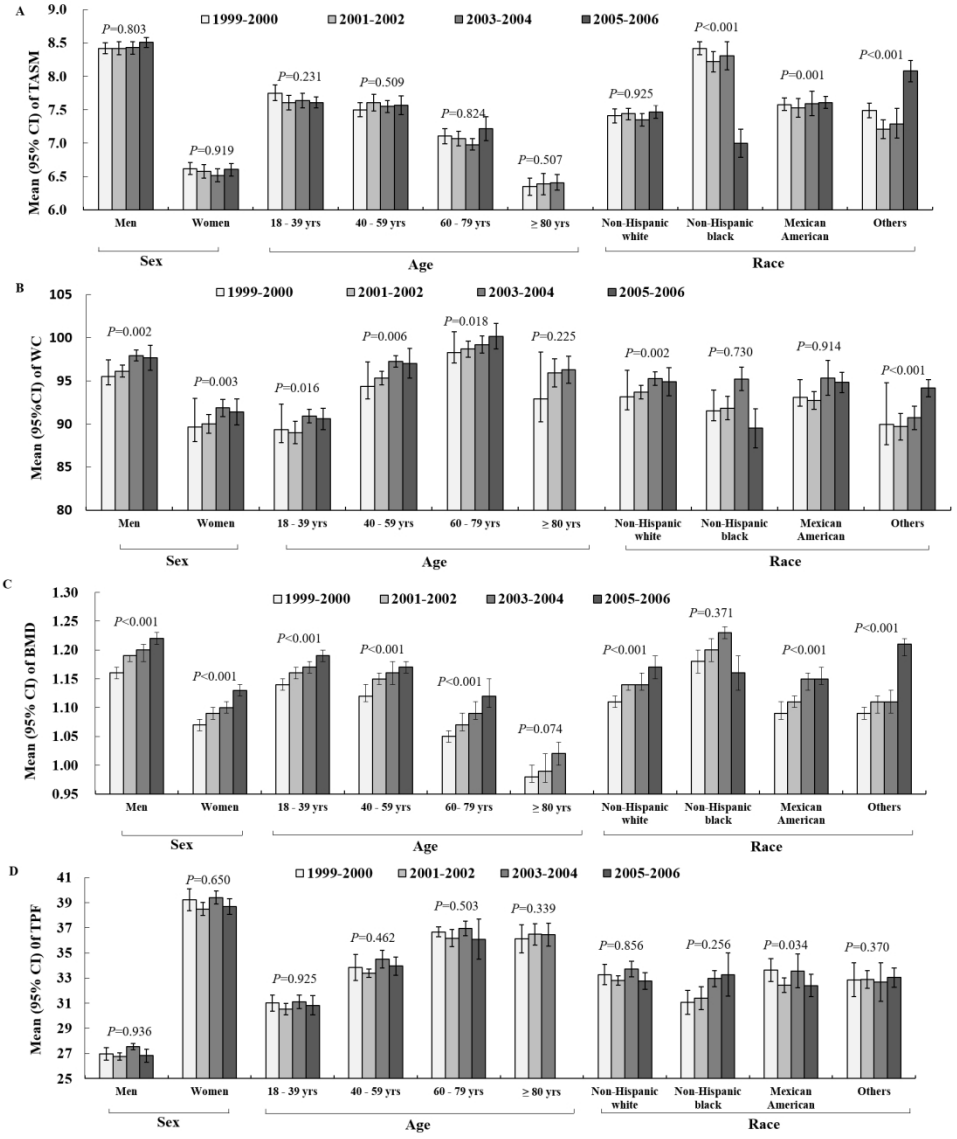

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STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	Page: 1, 3	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	Page: 5-6	Explain the scientific background and rationale for the investigation being reported
Objectives	Page: 6	State specific objectives, including any prespecified hypotheses
Methods		
Study design	Page: 6	Present key elements of study design early in the paper
Setting	Page: 6	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	Page: 6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants
Variables	Page: 6-7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	Page: 6-7	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	Page: 7-8	Describe any efforts to address potential sources of bias
Study size	Page: 6	Explain how the study size was arrived at
Quantitative variables	Page: 7-8	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	Page: 7-8	(a) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses
Results		
Participants	Page: 8	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	Page: 8-9	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
Outcome data	Page:12, 15	Report numbers of outcome events or summary measures
Main results	Page: 12, 15	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	Page: 12	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity

		analyses
Discussion		
Key results	Page: 17	Summarise key results with reference to study objectives
Limitations	Page: 19-20	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	Page:17-20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	Page: 18	Discuss the generalisability (external validity) of the study results
Other information		
Funding	Page: 21	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Prevalence and Temporal Trends of Pre-sarcopenia Metrics and Related Body Composition Measurements from the 1999-2006 NHANES survey

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Abstract

Objective: To evaluate the prevalence and temporal trends of pre-sarcopenia and related body composition measurements.

Design: Cross-sectional study.

Setting: National Health and Nutrition Examination Survey (NHANES) 1999-2006.

Methods: Pre-sarcopenia was defined according to the guidelines from the European Working Group on Sarcopenia. Logistic or linear regression models were used to evaluate the linear trend of the prevalence of pre-sarcopenia, obesity, and related body composition measurements.

Participants: A total of 29,947 participants aged 18 - 90 years from five waves of the NHANES were included in the analysis.

Outcome measures: Pre-sarcopenia was sex-specifically defined as having a skeletal mass index ≤ 7.26 kg/m^2 in men and ≤ 5.5 kg/m^2 in women. Body composition measurements, including total body fat percentage, total body fat mass, total lean body mass, appendicular skeletal muscle mass (ASM) and bone mineral density (BMD), were obtained by dual energy X-ray absorptiometry.

Results: The overall prevalence of pre-sarcopenia ranged from 16.4% in 1999-2000 to 14.8% in 2005-2006 (*P* for trend=0.78). Pre-sarcopenia was stable in both males (*P* for trend=0.36) and females (*P* for trend=0.20). The pre-sarcopenia prevalence was significantly elevated among the 18- to 39-year-old age group (from 11.3% to 14.1%, *P* for trend = 0.04) and among non-Hispanic blacks (*P* for trend < 0.001). Adults aged ≥ 80 years old had the highest prevalence.

Conclusions: The prevalence of pre-sarcopenia increased among young individuals over time. Non-Hispanic blacks also demonstrated an increasing trend in the prevalence over time.

Keywords: Pre-sarcopenia Metrics; Body Composition; Temporal Trends.

Strengths and limitations of this study

- We used the data from the nationally representative population-based surveys of the NHANES (1999-2006).
- Body composition measurements were obtained by the gold standard dual energy X-ray absorptiometry.
- Appendicular skeletal muscle mass rather than muscle strength and physical performance was assessed.
- The prevalence of pre-sarcopenia in women may be underestimated when using a height-adjusted definition of pre-sarcopenia.
- Reporting bias may exist due to self-reported physical activity data.

INTRODUCTION

According to the 2010 European Working Group on Sarcopenia in Older People (EWGSOP), sarcopenia is defined as a cluster of geriatric conditions characterized by progressive and generalized loss of skeletal muscle mass and strength with a high risk of adverse outcomes, including poor quality of life, physical disability, and even death. [1] The prevalence of pre-sarcopenia (5.9%) and sarcopenia (4.4%) among adults aged 45 years and older is high in the Netherlands [2]. It has been conservatively estimated that sarcopenia affects more than 50 million people around the world and will increase by more than 200 million over the next 40 years. [3]

Currently, there are a variety of definitions for sarcopenia, none of which have been agreed upon, and the prevalence of the disease is highly dependent on the diagnostic criteria used. Among the three components of sarcopenia defined in the EWGSOP, muscle mass, muscle strength, and performance, muscle mass plays a critical role in the progression of sarcopenia, and low muscle mass has been identified as pre-sarcopenia. Sarcopenia, especially in the context low skeletal muscle mass, is mainly caused by ageing, decreased participation in physical activities, [4] malnutrition, [5 6] and endocrine and metabolic disorders. [7] These factors directly contribute to the loss of muscle mass, [8] influencing muscle strength and performance and leading to a lower metabolic rate and reduced physical activity, which often causes fat gain. The gained fat could lead to a further loss of muscle mass and strength via cytokine protein catabolism [9] and insulin resistance. [10] Thus, sarcopenia and its effects can be part of a spiralling process of declining health.

Sarcopenic obesity, defined as a loss in body lean mass but preservation or even an increase in body fat mass, can have serious health implications. Recent data has indicated that obesity affects more people of younger age due to physical inactivity. [11] Therefore, it is reasonable to hypothesize that the prevalence of pre-sarcopenia has increased accordingly.

Currently, there is a lack of evidence to support this statement. Numerous studies have reported that sarcopenia/low muscle mass is related to frailty, [12] inflammation, [13 14] liver fibrosis, [15 16] cirrhosis, [17 18] systemic sclerosis, [19] cancer, [20-22] chronic obstructive pulmonary disease, [23] cardiovascular disease (CVD), [24 25] and mortality, [26] all of which place considerable health and economic burdens on public health care services. Thus, it is important to depict the prevalence and temporal trends of pre-sarcopenia and related body composition measurements over time in relation to sex, age, and race to better inform public health policy and prevention strategies.

In this study, we estimated the population-based prevalence and temporal trends of pre-sarcopenia metrics and related body composition measurements among adults in the United States (U.S.) from 1999 to 2006 by using data from the National Health and Nutrition Examination Survey (NHANES).

METHODS

Study design and participants

The NHANES is a nationally representative cross-sectional survey among non-institutionalized civilians in the U.S. [27] This analytical study involved participants aged 18 years and older from the NHANES cohort surveyed across four consecutive cycles: 1999-2000 (*n*=3,559), 2001-2002 (*n*=4,047), 2003-2004 (*n*=3,771), and 2005-2006 (*n*=3,071). All NHANES protocols were approved by the National Centre for Health Statistics Research ethics review board. All participants provided written informed consent.

Body component measurements and pre-sarcopenia

Physical examinations were conducted in mobile examination centres. Weight in kilograms, height in centimetres, and waist circumference (WC) in centimetres were measured using standardized techniques and equipment. Body mass index (BMI) was calculated as

weight in kilograms divided by the square of the height in metres. Overweight was defined as a BMI between 25.0-29.9 and obesity as a BMI of 30.0 or higher. [28] Central obesity was defined as having a WC of > 102 cm for males and > 88 cm for females. [29] Total body fat percentage, total body fat mass, total lean body mass, appendicular skeletal muscle mass (ASM) and bone mineral density (BMD) were measured using dual energy X-ray absorptiometry (DXA) in the four surveys from 1999 to 2006. The total appendicular skeletal muscle mass index (TASM) was calculated as the ASM divided by the height squared (kg/m^2). Pre-sarcopenia was sex-specifically defined as having a TASM $\leq$ 7.26 kg/m^2 in men and $\leq$ 5.5 kg/m^2 in women. [30]

Physical activity and social-demographic factors

Participants' sex, age, race, education level, annual household income, time spent watching television per day, and level of physical activity were collected by household interviews. Age was grouped into three categories: 18 to 39 years old, 40 to 59 years old, and 60 years or older. Race was classified as non-Hispanic white, non-Hispanic black, Mexican American, and others. Educational level was categorized into < high school graduate, high school graduate/general equivalency diploma, or ≥ college. Time spent watching TV per day was grouped into < 2 h, 2–4 h, or > 4 h. Annual household income was grouped into < $25000, $25000 to $55000, or > $55000. Physical activity was grouped into two levels: moderate/below or vigorous.

Statistical analyses

Participants' characteristics, including sex, age, race, education level, annual household income, time spent watching TV per day and level of physical activity, are shown as unweighted frequencies and weighted percentages with 95% confidence intervals. Weighted means and corresponding 95% confidence intervals of body weight, BMI and obesity, WC

and central obesity, total body fat percentage, total lean body mass, ASM, TASM, and BMD were calculated, and mean changes with 95% confidence intervals (CIs) of all these variables from 1999-2000 to 2005-2006 were calculated.

The age- and sex-adjusted prevalence of pre-sarcopenia was calculated for the four survey cycles from 1999-2000 to 2005-2006 for the overall sample and the sex, age, race, education level, annual household income, time spent watching TV per day, and physical activity level subgroups. The temporal trends of pre-sarcopenia prevalence, obesity and different body composition measurements, including TASM, WC, BMD, and TPF, for the overall sample and within the subgroups were assessed by survey-weighted linear (for continuous outcomes) or logistic (for binary outcomes) regression models with survey year as a continuous (ordered categorical) independent variable after adjustment for sex, age, race, education level, annual household income, time spent watching TV per day, and physical activity level [31 32].

Sampling weights were used to account for unequal probabilities of selection and nonresponses for all analyses, thereby providing estimates representative of the non-institutionalized civilian U.S. population. All statistical analyses were performed using SAS for Windows version 9.4 (SAS Institute, Cary, NC, USA). A two-sided $P < 0.05$ was considered statistically significant.

Patient and public involvement

There was no patient or public involvement in this study.

RESULTS

A total of 14,448 participants were included in this study, with 3,559 from 1999-2000, 4,047 from 2001-2002, 3,771 from 2003-2004, and 3,071 from 2005-2006 (**Table 1**). The distributions of the participants' characteristics across the four survey cycles were comparable.

In 1999-2000, 49.6% of the participants were women, 19.5% were 60 years or older, and 71.7% were non-Hispanic white. The proportion of patients with a vigorous physical activity level showed a significantly decreasing trend from 1999 to 2006 (P <0.001).

174 **Table 1. Participants' characteristics (weighted) from the NHANES surveys, 1999-2006**

Characteristics	No. weighted (%)			
	1999-2000 (*n* = 3559)	2001-2002 (*n* = 4047)	2003-2004 (*n* = 3771)	2005-2006 (*n* = 3071)
Sex				
Men	1829 (50.4) [48.4, 52.5]	2106 (50.0) [48.6, 51.3]	1932 (49.5) [47.5, 51.6]	1574 (49.7) [48.0, 51.5]
Women	1730 (49.6) [47.5, 51.7]	1941 (50.0) [48.7, 51.4]	1839 (50.5) [48.4, 52.6]	1497 (50.3) [48.5, 52.0]
Age group, mean (SD) [95% CI]	43.3 (0.5) [42.1, 44.4]	43.6 (0.5) [42.5, 44.7]	44.2 (0.6) [43.0, 45.4]	41.4 (0.4) [40.5, 42.4]
18 – 39 yrs	1493 (47.3) [44.7 49.9]	1704 (44.0) [39.9, 48.1]	1592 (42.4) [38.5, 46.3]	1540 (44.9) [41.9, 47.8]
40 – 59 yrs	964 (33.2) [31.1 35.4]	1217 (38.2) [34.8, 41.7]	1015 (38.0) [34.7, 41.3]	1067 (43.8) [41.6, 46.4]
60– 79 yrs	913 (17.1) [14.7, 19.4]	887 (15.2) [13.8, 16.7]	915 (16.7) [15.1, 18.3]	464 (11.3) [9.3, 13.3]
≥ 80 yrs	189 (2.4) [1.9, 2.8]	239 (2.6) [2.1, 2.0]	249 (2.9) [2.2. 3.5]	--
Race				
Non-Hispanic white	1513 (71.7) [65.5, 77.9]	2014 (72.4) [67.5, 77.4]	1915 (73.2) [65.9, 80.5]	1321 (71.1) [65.1, 77.1]
Non-Hispanic black	642 (9.5) [6.25, 12.8]	785 (10.1) [6.9, 13.2]	796 (10.5) [6.6, 14.3]	128 (5.1) [3.4, 6.9]
Mexican American	1082 (6.6) [3.6, 9.5]	960 (7.7) [5.7, 9.7]	799 (7.7) [3.7, 11.7]	746 (8.90) [6.3, 11.5]
Others	322 (12.2) [5.8, 18.6]	288 (9.8) [5.8, 13.9]	261 (8.7) [6.3, 11.0]	876 (14.8) [10.9, 18.8]
Education level				
< High school graduate	1408 (23.6) [20.4, 26.7]	1300 (19.2) [17.0, 21.4]	1114 (17.8) [15.0, 20.5]	662 (15.5) [11.9, 19.2]
High school graduate/GED	840 (26.4) [22.4, 30.4]	980 (25.5) [23.3, 27.7]	978 (26.9) [24.7, 29.1]	618 (24.5) [22.1, 26.9]
≥ College	1302 (50.0) [45.8, 54.2]	1763 (55.3) [51.9, 58.7]	1675 (55.3) [52.0, 58.7]	1363 (60.0) [55.2, 64.9]
Annual household income				
< $25000	1452 (36.7) [29.6, 43.8]	1479 (29.7) [27.1, 32.3]	1518 (30.6) [26.7, 34.3]	920 (20.9) [17.6, 24.2]
$25000 – $55000	902 (30.8) [26.8, 34.8]	1163 (30.9) [27.5, 34.3]	1081 (32.0) [27.5, 36.5]	934 (30.6) [27.2, 34.1]
> $55000	731 (32.5) [26.7, 38.2]	1133 (39.4) [35.6, 43.1]	958 (37.4) [32.2, 42.7]	1097 (48.5) [43.6, 53.5]
Time spent watching TV per day, mean (SD) [95% CI]	2.34 (0.03) [2.28, 2.41]	2.31 (0.04) [2.24, 2.39]	2.16 (0.05) [2.06, 2.27]	2.07 (0.05) [1.97, 2.17]
< 2 h	621 (19.5) [17.7, 21.6]	606 (19.8) [17.9, 21.6]	634 (22.0) [19.3, 24.8]	545 (22.5) [20.8, 24.2]
2-4 h	2072 (68.3) [66.7, 69.9]	2215 (63.2) [61.4, 65.2]	2040 (64.7) [61.5, 67.9]	1674 (66.8) [65.0, 68.5]
> 4 h	428 (12.2) [10.7, 13.8]	674 (17.0) [15.6, 18.4]	542 (13.3) [10.7, 15.9]	354 (10.7) [8.49, 13.0]
Physical activity level				
Moderate or below	888 (44.0) [40.1, 47.8]	1236 (51.0) [47.0, 55.0]	1451 (61.5) [58.4, 64.6]	1066 (54.0) [51.0, 57.0]
Vigorous	1013 (56.0) [52.2, 59.9]	1253 (49.0) [45.0, 53.0]	963 (38.5) [35.5, 41.6]	1027 (46.0) [43.1, 49.0]
Body mass index				
Normal or below (< 25 kg/m^2)	1351 (40.1) [36.3, 43.9]	1617 (39.6) [38.0, 41.2]	1389 (36.6) [34.6, 38.6]	1089 (36.6) [33.1, 40.2]

Overweight (25.0-29.9 kg/m²)	1289 (35.5) [32.7, 38.3]	1494 (36.7) [34.2, 39.3]	1348 (35.8) [32.9, 38.6]	1054 (34.1) [32.4, 35.9]
Obesity (≥ 30 kg/m²)	914 (24.4) [21.3, 27.5]	936 (23.7) [21.3, 26.0]	1034 (27.6) [24.7, 30.5]	928 (29.3) [25.8, 32.7]

--: Not available.

Prevalence and temporal trends of pre-sarcopenia from 1999 to 2006

The overall age- and sex-adjusted prevalence of pre-sarcopenia ranged from 16.4% (95% CI: 15.3%, 17.6%) in 1999-2000 to 14.8% (95% CI: 13.0%, 16.8%) in 2005-2006 (*P* for trend = 0.78) (**Table 2)**.

The age-adjusted prevalence of pre-sarcopenia in men was 22.7% (95% CI: 20.3%, 25.2%) in 1999-2000 and 12.3% (95% CI: 10.6%, 14.3%) in 2005-2006 (*P* for trend = 0.36), while in women, the prevalence was 20.0% in 1999-2000 and 17.7% in 2005-2006 (*P* for trend = 0.20). The prevalence of pre-sarcopenia in women was significantly higher than that in men in 2005-2006 (17.7% for women vs. 12.3% for men; $P < 0.001$). There were also racial differences in pre-sarcopenia prevalence as well as temporal trends. The prevalence significantly increased from 6.2% in 1999-2000 to 20.6% in 2005-2006 among non-Hispanic blacks (*P* for trend < 0.001) but remained stable among non-Hispanic whites (*P* for trend = 0.84) and Mexican Americans (*P* for trend = 0.54) from 1999 to 2006. Compared to those in the other age groups, participants aged ≥ 80 years and 60 – 79 years had a significantly higher prevalence of pre-sarcopenia in the four survey cycles from 1999-2006. In three of the survey cycles (1999-2000, 2001-2002, and 2003-2004), compared to those who reported moderate/low physical activity levels, participants who reported vigorous physical activity levels were more likely to have a lower prevalence of pre-sarcopenia (*P* values < 0.01). In addition, participants with higher annual household incomes had a lower prevalence of pre-sarcopenia in the 2001-2002 and 2003-2004 survey cycles. In all four survey cycles, participants with BMI < 25 kg/m^2 had a relatively higher prevalence of pre-sarcopenia than overweight and obese participants.

Table 2. Prevalence (95% CIs) and temporal trends of pre-sarcopenia in the NHANES surveys from 1999 to 2006

Characteristics	1999-2000 (n=3550)	2001-2002 (n=3987)	2003-2004 (n=3745)	2005-2006 (n=3062)	*P*-value for trend #
Overall	16.4 (15.3, 17.6)	16.4 (14.0, 19.1)	17.9 (16.2, 19.7)	14.8 (13.0, 16.8)	0.78
Sex					
Men	22.7 (20.3, 25.2)	19.7 (15.9, 24.2)	21.2 (18.8, 23.7)	12.3 (10.6, 14.3)	0.36
Women	20.0 (17.9, 22.3)	21.4 (17.7, 25.5)	23.0 (19.8, 26.6)	17.7 (14.9, 20.9)	0.20
***P* for sex**	0.45	0.23	0.23	< 0.001	
Age group					
18 – 39 yrs	11.3 (9.1, 14.0)	13.5 (10.6, 17.0)	14.9 (12.8, 17.3)	14.1 (11.8, 16.8)	0.04
40 – 59 yrs	15.1 (12.9, 17.5)	12.1 (9.9, 14.7)	14.2 (11.6, 17.2)	12.9 (11.0, 15.2)	0.25
60 – 79 yrs	22.3 (19.0, 26.1)	23.7 (18.7, 29.6)	23.6 (20.3, 27.2)	17.7 (14.4, 21.5)	0.38
≥ 80 yrs	45.1 (38.7, 51.6)	40.1 (31.8, 49.0)	42.0 (36.2, 48.0)	--	0.64
***P* for age group**	< 0.001	< 0.001	< 0.001	0.05	
Race					
Non-Hispanic white	22.8 (21.3, 24.5)	20.5 (17.5, 23.9)	22.9 (20.3, 25.6)	15.9 (13.8 (18.3)	0.84
Non-Hispanic black	6.2 (4.2, 8.9)	10.8 (7.2, 15.8)	8.6 (5.8, 12.5)	20.6 (13.0, 31.1)	< 0.001
Mexican American	20.5 (17.3, 24.3)	20.9 (16.4, 26.2)	20.9 (17.1, 25.3)	14.9 (11.7, 18.8)	0.54
Others	22.3 (15.1, 31.6)	31.0 (23.1, 40.2)	32.7 (26.6, 38.0)	6.9 (5.0, 9.6)	0.13
***P* for Race**	< 0.001	< 0.001	< 0.001	< 0.001	
Education level,					
< High school graduate	20.7 (17.5, 24.4)	21.1 (14.9, 28.9)	22.7 (19.1, 26.7)	16.6 (13.3, 20.5)	0.34
High school graduate or GED	21.3 (18.2, 24.7)	22.0 (17.6, 27.1)	21.2 (19.0, 23.5)	14.0 (11.6, 16.8)	0.47
≥ College	21.6 (19.2, 24.4)	19.4 (16.5, 22.7)	22.3 (18.9, 26.1)	14.4 (12.3, 16.8)	0.59
***P* for education**	0.88	0.22	0.57	0.50	
Annual household income					
< $25000	23.0 (20.0, 26.3)	24.5 (18.5, 31.7)	26.2 (23.5, 29.2)	15.3 (12.5, 18.6)	0.51
$25000 – $55000	19.7 (16.7, 23.2)	20.9 (17.0, 25.4)	22.1 (18.2, 26.5)	14.3 (11.6, 17.4)	0.77
> $55000	18.5 (15.1, 22.6)	15.4 (11.4, 20.4)	16.9 (13.1, 21.5)	14.9 (12.5, 17.7)	0.94
***P* for income**	0.17	0.005	< 0.001	0.80	
Time spent watching TV per day					
< 2 h	23.0 (17.6, 29.5)	21.1 (18.4, 24.2)	19.7 (14.8, 25.7)	14.3 (11.2, 18.1)	0.48
2-4 h	20.4 (18.8, 22.2)	21.5 (17.9, 25.7)	23.3 (21.1, 25.6)	14.5 (12.0, 17.3)	0.76
> 4 h	24.8 (19.2, 31.4)	20.5 (16.3, 25.6)	23.5 (18.9, 28.9)	13.6 (10.8, 16.9)	0.17
***P* for time spent watching TV**	0.42	0.68	0.08	0.95	
Physical activity level					

Moderate or below	20.3 (17.5, 23.5)	23.4 (19.2, 28.1)	22.2 (18.7, 26.1)	14.7 (11.7, 18.3)	0.35
Vigorous	15.2 (12.1, 18.8)	15.3 (11.9, 19.3)	16.4 (13.1, 20.4)	12.7 (9.8, 16.3)	0.15
***P* for physical activity level**	0.001	< 0.001	0.002	0.38	
Body mass index					
Normal or below (< 25 kg/m^2)	50.7 (45.3, 56.1)	49.7 (42.1, 57.3)	56.4 (50.4, 62.3)	41.4 (36.0, 46.9)	0.42
Overweight (25.0-29.9 kg/m^2)	5.4 (3.8, 7.8)	5.9 (4.1, 8.5)	7.2 (5.9, 8.8)	4.8 (3.4, 6.7)	0.08
Obesity (≥ 30 kg/m^2)	0.4 (0.2, 1.0)	0.3 (0.1, 1.2)	0.2 (0.1, 0.9)	--	0.30
***P* for body mass index**	<0.001	<0.001	<0.001	<0.001	

--: Not available.

Pre-sarcopenia was defined according to dual energy X-ray absorptiometry (DXA) criteria: GED, general equivalency diploma.

[#]: *P*-value for trend (1999-2006) was calculated by using logistic regression models adjusted for sex, age, race, education level, annual household income, time spent watching TV per day, and physical activity level.

P-values for the differences between groups in each survey cycle were obtained by the chi-squared test.

Body Composition Measurements

The average body weight across all participants significantly increased from 76.8 kg (95% CI: 75.6, 77.9) in 1999-2000 to 78.9 kg (95% CI: 77.4, 80.4) in 2005-2006 (*P* for trend =0.010), with an average increase of 2.11 kg (95% CI: 0.28, 3.93 kg) (**Table 3**). Correspondingly, the prevalence of obesity significantly increased from 24.3% (95% CI: 21.2%, 27.4%) to 29.3% (95% CI: 25.8%, 32.7%) in the overall population (*P* for trend = 0.023) and from 20.8% (95% CI: 17.9%, 23.7%) to 27.6% (95% CI: 23.0%, 32.1%) in men (*P* for trend=0.007) but remained stable in women (from 28.0% to 30.9%, *P* for trend=0.229) over time (**Table 3 and Figure 1A**). After stratification by age (**Figure 1B**), the prevalence of obesity significantly increased from 25.6% to 33.8% in the 40-59 age group (*P* for trend=0.027) but remained stable in the other three age groups. Similar increasing trends of obesity prevalence were observed in non-Hispanic whites (from 23.8% to 28.6%, *P* for trend =0.025) but were statistically stable in non-Hispanic blacks and Mexican Americans (**Figure 1C**). From 1999 to 2006, the TASM significantly decreased in the non-Hispanic black group but significantly increased in the Mexican American and other ethnic groups (**Table 3 and Figure 2A**). Meanwhile, we observed a slight increase in waist circumference **(Table 3 and Figure 2B)**, total lean body mass **(Table 3)**, prevalence of central obesity **(Table 3)**, and BMD (**Table 3 and Figure 2C**), however, we did not detect any significant trends for TPF (**Figure 2D**).

Table 3. Trends in body weight, obesity and other body composition measurements from 1999 to 2006 in the NHANES surveys

Characteristics	Survey cycles				*P* -value for trend #	Mean change from 1999-2000 to 2005-2006 (95% CI)
	1999-2000	2001-2002	2003-2004	2005-2006		
Weight, kg	76.8 (75.6, 77.9)	76.9 (76.1, 77.7)	78.3 (77.5, 79.0)	78.9 (77.4, 80.4)	0.010	2.11 (0.28, 3.93)
BMI, kg/m²	26.9 (26.5, 27.3)	26.8 (26.6, 27.1)	27.3 (27.0, 27.5)	27.5 (27.0, 28.0)	0.016	0.59 (-0.01, 1.20)
Overweight, % †	35.5 (32.6, 38.2)	36.7 (34.2, 39.3)	35.8 (32.9, 38.6)	34.1 (32.4, 35.9)	0.25	-1.31 (-4.45, 1.83)
Obesity, % †	24.3 (21.2, 27.4)	23.7 (21.3, 26.0)	27.6 (24.7, 30.5)	29.3 (25.8, 32.7)	0.023	4.92 (0.49, 9.36)
Waist Circumference, cm	92.6 (91.3, 93.9)	93.0 (92.4, 93.7)	94.9 (94.3, 95.5)	94.5 (93.1, 95.9)	<0.001	1.90 (0.12, 3.67)
Central obesity, % †	39.9 (35.3, 44.5)	41.5 (39.3, 43.8)	47.3 (44.5, 50.2)	45.1 (41.2, 49.1)	0.005	5.21 (-0.60, 11.0)
Total body fat percentage, %	33.0 (32.4, 33.7)	32.6 (32.3, 32.9)	33.5 (33.1, 34.0)	32.8 (32.3, 33.3)	0.766	-0.24 (-1.04, 0.56)
Total lean body mass, kg	49.3 (48.7, 49.8)	49.6 (49.1, 50.0)	49.8 (49.3, 50.3)	50.7 (50.0, 51.5)	<0.001	1.45 (0.57, 2.34)
ASM, kg *	21.7 (21.5, 22.0)	21.7 (21.4, 22.0)	21.7 (21.4, 21.9)	21.9 (21.6, 22.2)	0.986	0.16 (-0.24, 0.56)
SMI, kg/m²	7.53 (7.45, 7.61)	7.50 (7.41, 7.59	7.46 (7.38, 7.54)	7.55 (7.46, 7.64)	0.958	0.02 (-0.09, 0.14)
BMD, g/cm²	1.12 (1.11, 1.12)	1.14 (1.13, 1.14)	1.15 (1.14, 1.16)	1.17 (1.16, 1.19)	< 0.001	0.06 (0.04, 0.07)

ASM: Appendicular skeletal muscle mass, TASM: Total appendicular skeletal muscle index, BMD: Bone mineral density;

#: *P*-value for trend (1999-2006) was adjusted for sex, age, race, education level, annual household income, time spent watching TV per day, and physical activity level.

All statistics were weighted and shown as the means (95% confidence interval) or † percentages (95% confidence intervals).

DISCUSSION

In this large-scale study that analysed nationally representative data from U.S. respondents to the NHANES, we found that the overall prevalence of pre-sarcopenia remained stable, while there was a substantial increase in the prevalence for the non-Hispanic black and young age groups from 1999 to 2006. Hence, our hypothesis regarding an increasing trend in the pre-sarcopenia prevalence over time was not fully supported by the findings. Our results indicate that certain subpopulations might be more vulnerable to pre-sarcopenia than the overall population. Indeed, we found that individuals who were older or under/normal weight had a considerably higher prevalence of pre-sarcopenia.

Our study found an increasing trend in the prevalence of obesity and central obesity from 1999 to 2006 among the overall population. Previous studies reported that obesity can lead to loss of muscle mass and strength [33] and is commonly accompanied by a reduction in physical activity and deterioration of metabolic disorders, which in turn accelerates the abnormal distribution of fat mass and initiates the process of sarcopenia. [34] In contrast, it is interesting that the prevalence of pre-sarcopenia was considerably higher in under/normal weight adults than in obese adults in our study. The contradictory findings might be explained by the fact that our study only measured skeletal muscle mass, but the muscle mass of under/normal weight individuals might be relatively lower than that of overweight/obese individuals. In addition, our study focused on pre-sarcopenia rather than sarcopenia, which is defined as the presence of both low muscle mass and low muscle function (strength or physical performance).

A previous study reported that skeletal muscle mass begins to decrease at approximately 30 – 39 years old. [35] Accordingly, we found a relatively higher prevalence of pre-sarcopenia in the older age groups than in the 18-39 age group. However, it is still unclear whether muscle mass reduction would further accelerate muscle strength loss and ageing-

related health issues. Observational studies have reported a linearly positive association between muscle mass and strength in both middle-aged and elderly people. [36-38] This indicates that the amount of muscle mass acquired during youth may protect adults from the early onset of sarcopenia. Therefore, it may be beneficial to pay more attention to increasing muscle mass in both young and old populations. The peak period of muscle strength lags nearly 10 years behind the peak period of muscle mass and starts to decline at approximately 50 years of age. [39] The speed of muscle strength decline is 2 to 5 times faster than that of muscle mass over the same period.[40]

We found that the prevalence of pre-sarcopenia was stable in both genders from 1999 to 2006. It was also found that women had a higher prevalence of pre-sarcopenia than men in 2005-2006. This might be caused by a more rapid decrease in the prevalence of pre-sarcopenia among men than women. Previous evidence, however, is inconsistent. For instance, the study of Michele *et al.* found a higher prevalence of sarcopenia in men than in women who were aged 64 to 93 years, [41] while the findings in the Fifth Korea National Health and Nutrition Examination Survey showed that sarcopenia was more prevalent in women. [42] Women have less absolute and relative muscle mass than men. [43] In addition, given the natural differences in skeletal muscle between men and women, such as the amount of muscle mass, muscle capillary density, and muscle fibre type, [44] physical activity might be a potential cause for sex differences in the prevalence of sarcopenia. [45] In our study, most women had lower self-reported levels of physical activity than men. Vigorous physical activity in men gradually increased, whereas it decreased in women over time. Another critical factor is age-related changes in gonadal function and sex hormones regulating muscle mass distribution. Evidence suggests that lower serum testosterone levels in elderly men contribute to muscle weakness. [46] Men experience a gradual decrease in knee extensor and handgrip strength between 20 and 80 years of age, whereas women experience a steep decline

after the age of 55 (menopausal age). [47 48] Although it is not clear whether age-related changes in gonadal function directly regulate physical activity in humans, gonadectomy has been shown to cause a dramatic decline in spontaneous physical activity in animals. [49] Thus, sex differences might be pivotal in understanding the process of sarcopenia and ageing, and understanding why each sex remains "muscle healthy" throughout their lifespan could open new avenues to prevent sarcopenia and the ageing process.

We also detected a considerably increased trend of pre-sarcopenia prevalence in non-Hispanic black people, while the prevalence was stable in non-Hispanic whites and Mexican Americans over time. Racial differences in muscle mass have been reported in previous studies. Evidence has shown that African Americans have a significantly higher skeletal muscle/adipose tissue-free body mass ratio than other races, although the difference was very small. [50] Mahbubur and Abbey reported that black women had greater levels of total and regional lean mass than white and Hispanic women and that Hispanic women had even lower values than white women in an assessment of the body composition of 708 healthy black, white, and Hispanic women aged 16–33 years using DXA analysis. [51] According to the NHANES III bioelectrical impedance data, the amount of fat-free mass in Mexican Americans was lower than that in non-Hispanic Blacks, which was in turn lower than that in non-Hispanic Whites. [52] The underlying mechanism of these racial differences is still unclear and warrants further investigation.

This is a representative population-based study. This is the first study that focused on pre-sarcopenia among adults. However, there are several limitations in this study. First, we only assessed muscle mass data rather than muscle strength, which does not reflect muscle power and may be confounded by a third variable that was not involved in this study. Second, the prevalence of pre-sarcopenia in women may be underestimated because we used a height-adjusted definition of the condition, [53] which is potentially problematic in identifying

participants with sarcopenic obesity. [54] However, if we had used the weight-adjusted definition, people classified as having pre-sarcopenia would have had higher BMI values compared with those without sarcopenia. [55] Third, as physical activity data were self-reported, reporting bias may exist. Recent research on self-reported levels of physical activity indicated that individuals in the U.S. tended to have differing perceptions of activity levels and that compared to Europeans, U.S. individuals overestimate their time spent exercising. [56] Future studies should apply objective measures to determine muscle strength and physical activity to accurately evaluate sarcopenia prevalence.

CONCLUSIONS

The overall prevalence of pre-sarcopenia was stable in both men and women from 1999-2006 among U.S. adults, while there is a slight increase in the prevalence of pre-sarcopenia from 1999 to 2006 among U.S. young adults. Adults who were non-Hispanic blacks, elderly or under/normal weight are at high-risk of pre-sarcopenia. Meanwhile, we found a significant increased trend of obesity, central obesity. It suggests that the high prevalence of pre-sarcopenia and obesity is an important public health concern. It might be helpful to maintain resistant and at least moderate physical activity for the prevention of sarcopenia and obesity in U.S. adults.

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Contributors

JBL, XZ and HJL designed and conducted the research; JBL, XZ and HJL analysed the data; JBL, XZ, HJL, YWW and DTG were responsible for the final content of the manuscript; all authors took part in writing the manuscript and read and approved the final version.

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Competing interests

None declared.

Patient consent for publication

Not required.

Provenance and peer review

Not commissioned; externally peer reviewed.

Ethics approval

All NHANES protocols were approved by the National Centre for Health Statistics Research ethics review board.

Data availability statement

The data link is https://www.cdc.gov/nchs/nhanes/index.htm.

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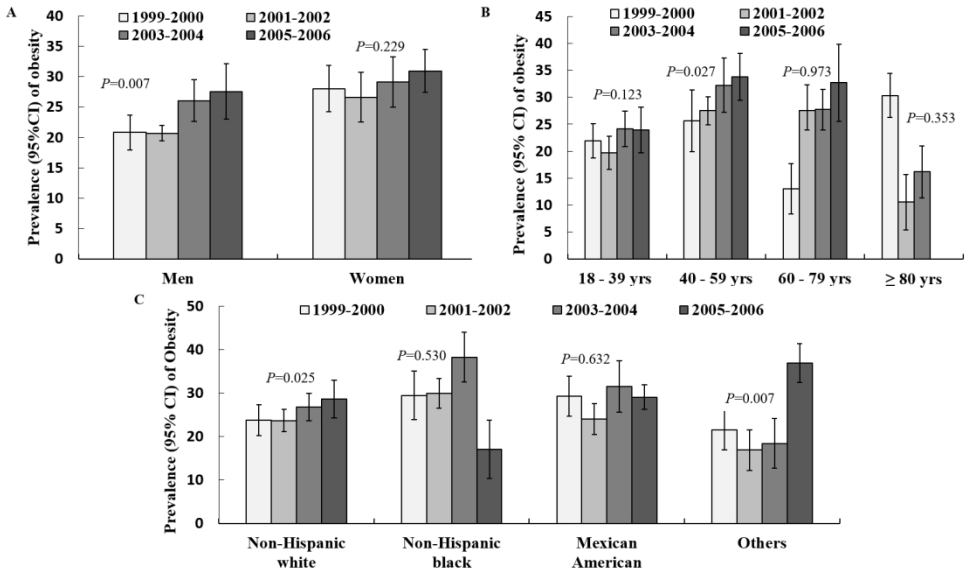
Figure Legends

Figure 1. Prevalence of obesity stratified by sex (A), age (B) and racial group (C) from 1999 to 2006 in the NHANES surveys. 95% CI: 95% confidence interval. P values refer to temporal trends obtained by logistic regression models after adjusting for sex, age, race, education level, annual household income, time spent watching TV per day, and physical activity level.

Figure 2. Distribution of body composition measurements, including SMI (A), WC (B), BMD (C), and TPF (D), by sex, age and racial group from 1999 to 2006. SMI: Skeletal muscle index; WC: Waist circumstance; BMD: Bone mineral density; TPF: Total percentage of body fat; 95% CI: 95% confidence interval. P values refer to temporal trends obtained by logistic regression models after adjusting for sex, age, race, education level, annual household income, time spent watching TV per day, and physical activity level.



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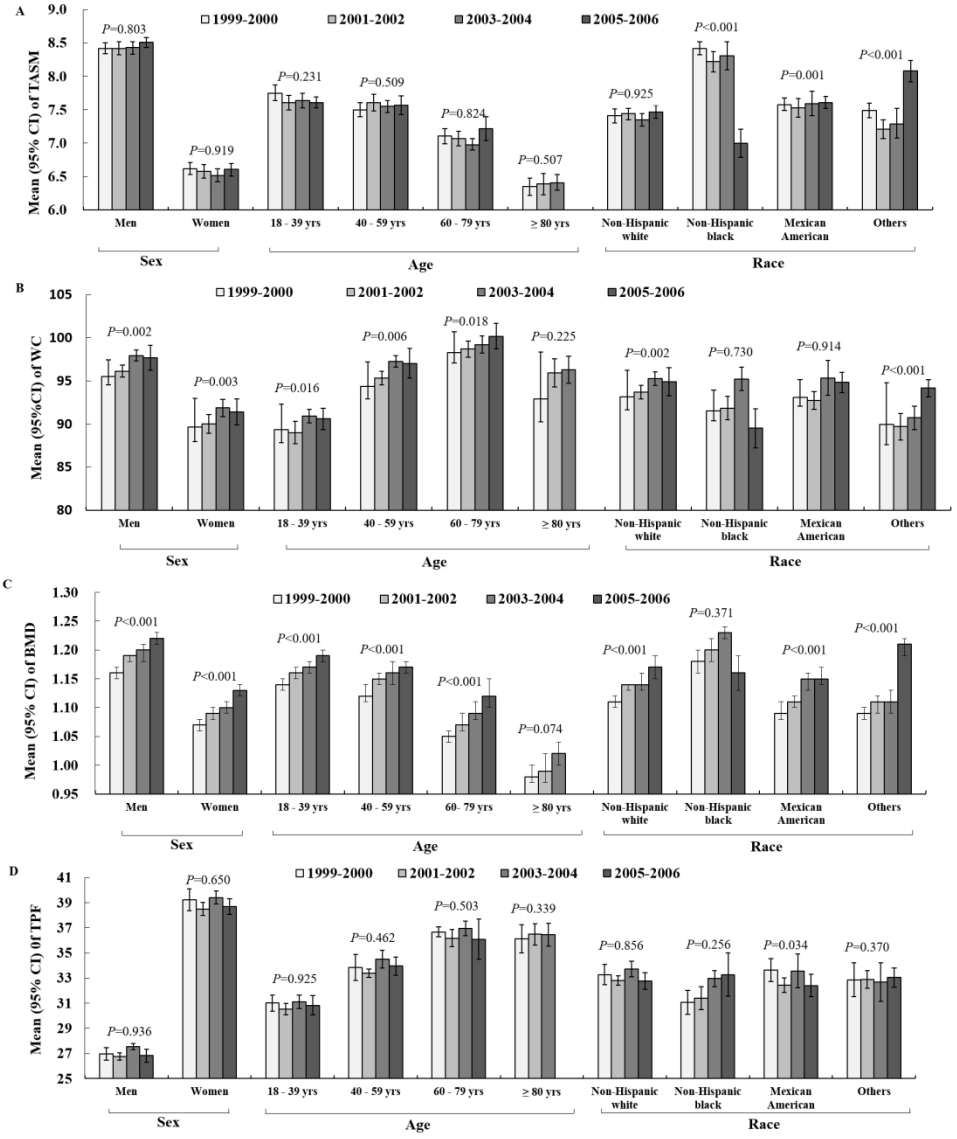

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325x376mm (150 x 150 DPI)

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	Page: 1, 3	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale	Page: 5-6	Explain the scientific background and rationale for the investigation being reported
Objectives	Page: 6	State specific objectives, including any prespecified hypotheses
Methods		
Study design	Page: 6	Present key elements of study design early in the paper
Setting	Page: 6	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	Page: 6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants
Variables	Page: 6-7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	Page: 6-7	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	Page: 7-8	Describe any efforts to address potential sources of bias
Study size	Page: 6	Explain how the study size was arrived at
Quantitative variables	Page: 7-8	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	Page: 7-8	(a) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses
Results		
Participants	Page: 8	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	Page: 8-9	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
Outcome data	Page:12, 15	Report numbers of outcome events or summary measures
Main results	Page: 12, 15	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	Page: 12	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity

		analyses
Discussion		
Key results	Page: 17	Summarise key results with reference to study objectives
Limitations	Page: 19-20	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	Page:17-20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	Page: 18	Discuss the generalisability (external validity) of the study results
Other information		
Funding	Page: 21	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.