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

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3 **Prevalence and Trends of Sarcopenia Metrics and Related Body Composition: data**
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5 **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 catabolism⁹ 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.

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

15 **Study design and participants**

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18 The NHANES is a nationally representative cross-sectional survey among civilian
19 non-institutionalized persons in the U.S..²⁷ This analytical study involved participants aged
20 18 years and older from the NHANES III cohort which ran from 1988-1994, followed by four
21 consecutive cycles: 1999-2000, 2001-2002, 2003-2004, and 2005-2006. All NHANES
22 protocols were approved by the National Center for Health Statistics Research ethics review
23 board. All participants provided written informed consent.
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32 **Body component measurements and sarcopenia**

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35 Physical examinations were conducted in mobile examination centers. Weight in
36 kilograms, height in centimeters, waist circumference (WC) in centimeters, and heart rate in
37 beats per minute were measured using standardized techniques and equipment. Body mass
38 index (BMI) was calculated as weight in kilograms divided by height in meters squared.
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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/m²). Sarcopenia was sex-
specifically defined as having a SMI of ≤ 7.26 kg/m² in men and ≤ 5.5 kg/m² 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 \geq 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 (17.6, 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 (16.9, 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% CI: 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/m ²	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/m ²	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/cm ²	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 ₂ max, 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, VO₂max 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 decrease 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

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2
3 prevalence. From 1999 to 2006, sarcopenia prevalence decreased in men but not in women.
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5 Previous evidence is controversial and inconsistent. Michele *et al.* compared 195 women
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7 aged 64 to 93 years old and 142 men aged 64 to 92 years old, they found a higher prevalence
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9 of sarcopenia in men than in women;⁴⁰ while in the Fifth Korea National Health and Nutrition
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11 Examination Survey, sarcopenia was more prevalent in women.⁴¹ Women have less absolute
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13 and relative muscle mass than men⁴² in biology. Besides natural differences in skeletal
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15 muscle between men and women, such as the amount of muscle mass, muscle capillary
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17 density, and muscle fiber type,⁴³ physical activity might be a potential cause for sex
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19 differences in sarcopenia prevalence.⁴⁴ In our study, most women had lower self-reported
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21 levels of physical activity than men. The amount of physical activity in men gradually
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23 increased, whereas it decreased in women over time. Another critical factor is age-related
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25 changes in the gonadal function and sex hormones regulating muscle mass distribution.
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27 Evidence suggested lower serum testosterone levels in elderly men contributes to muscle
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29 weakness.⁴⁵ Men experience a gradual decrease in knee extensor and handgrip strength
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31 between 20 and 80 years of age, whereas, women experience a steep decline after the age of
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33 55 (menopausal age).^{46 47} Although it is not clear whether age-related changes in the gonadal
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35 function directly regulate physical activity in humans, animals after gonadectomy can cause a
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37 dramatical decline in spontaneous physical activity.⁴⁸ Thus, sex differences might be pivotal
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39 in understanding the process of sarcopenia and aging, understanding why each sex remains
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41 “muscle healthy” throughout their lifespan could open new avenues to prevent and treat
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43 sarcopenia and the ageing process.
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51 We also detected an increased trend of sarcopenia prevalence, from 1.12% in 1999 to
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53 26.4% in 2006, in non-Hispanic black people, while the prevalence was stable in non-
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55 Hispanic Whites, Mexican Americans and other racial groups over time. Racial differences in
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57 muscle mass have been reported in previous studies. Evidence has shown African-Americans
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3 have significantly higher skeletal muscle/adipose tissue-free body mass ratio than other races,
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5 although the difference was very small.⁴⁹ Mahbubur and Abbey reported black women had
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7 greater levels of total and regional lean mass than White and Hispanic women, while
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9 Hispanic women had even lower values than white women after assessment of body
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11 composition of 708 healthy black, white, and Hispanic women aged 16–33 years using DXA
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13 analysis.⁵⁰ According to the NHANES III bioelectrical impedance data, the amount of fat-free
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15 mass in Mexican-Americans was lower than in non-Hispanic Blacks, which was lower than
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17 in non-Hispanic Whites.⁵¹ The underlying mechanism of racial differences is still unclear and
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19 warrants further investigation.
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24 There are several limitations of this study. First, we only accessed muscle mass data
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26 rather than muscle strength which does not reflect muscle power and may be confounded by a
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28 third variable that was not involved in this study. Second, the prevalence of sarcopenia in
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30 women may be underestimated because we used a height adjusted definition of sarcopenia⁵²
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32 which is potentially problematic in identifying participants with sarcopenic obesity.⁵³
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34 However, if we had used the weight-adjusted definition, people classified as having
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36 sarcopenia would have had higher BMI values compared with those without sarcopenia.⁵⁴
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38 Third, physical activity data was self-reported therefore bias may be a factor. Recent research
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40 on self-reported levels of physical activity indicated individuals in the U.S. tended to have
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42 differing perceptions of activity levels, overestimating their time spent exercising compared
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44 to Europeans.⁵⁵ Future studies should apply objective measures to muscle strength and
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46 physical activity to accurately evaluate sarcopenia prevalence.
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53 CONCLUSIONS

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56 Using data from the representative NHANES surveys covering nearly 20 years of data
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58 from 1999 to 2006, there was a youth-oriented tendency of prevalence of sarcopenia from
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3 1999 to 2006 among U.S. adults. Sarcopenia prevalence significantly decreased in men but
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5 not in women from 1999 to 2006. Together with an increase in obesity and central obesity,
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7 elevations of sarcopenia in non-Hispanic blacks and young people were observed. It is
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9 recommended to control body fat ratio and develop good habit of keeping resistant and
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11 moderate physical activity to prevent sarcopenia both for young and elderly people. The
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13 continued high prevalence of sarcopenia and obesity is an important public health concern.
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Contributors

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

Not required.

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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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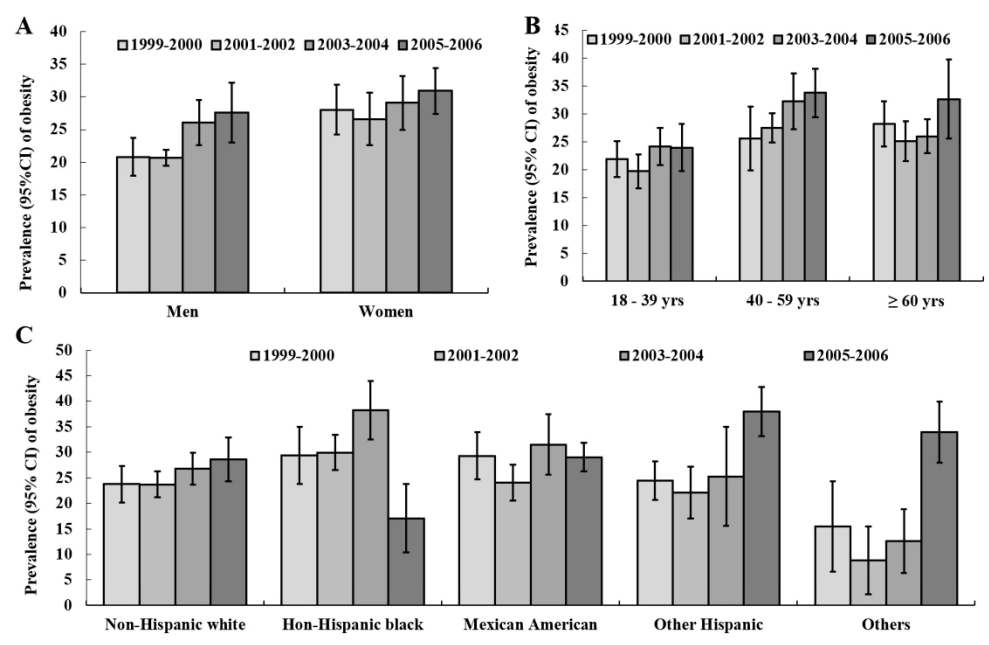
Figure Legends

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

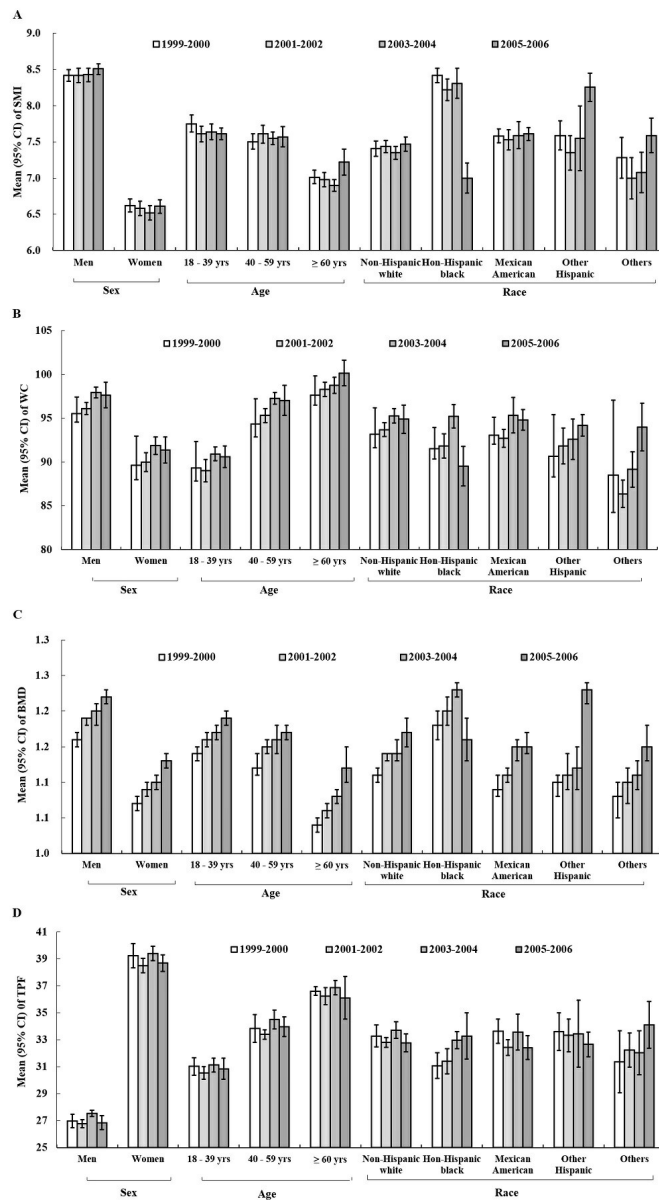
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Prevalence of obesity stratified by sex (A), age (B) and race groups (C) from 1988 to 2006 in the NHANES surveys

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

127x226mm (200 x 200 DPI)

BMJ Open

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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Keywords:	Body Composition, PUBLIC HEALTH, EPIDEMIOLOGY

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3 1 **Prevalence and Temporal Trends of Pre-sarcopenia Metrics and Related Body**
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32 Abstract

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

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

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

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

42 **Outcome measures:** Pre-sarcopenia was sex-specifically defined as having a skeletal mass
43 index ≤ 7.26 kg/m² in men and ≤ 5.5 kg/m² in women. Body compositions, including total
44 body fat percentage, total body fat mass, total lean body mass, appendicular skeletal muscle
45 mass (ASM) and bone mineral density (BMD) were measured by dual energy X-ray
46 absorptiometry.

47 **Results:** The overall prevalence of pre-sarcopenia ranged from 16.4% in 1999-2000 to 14.8%
48 in 2005-2006 (*P* for trend=0.78). Pre-sarcopenia were stable in both males (*P* for trend=0.36)
49 and females (*P* for trend=0.20). Pre-sarcopenia prevalence was significantly elevated among
50 18 – 39 years age group (from 11.3% to 14.1%, *P* for trend = 0.04) and among non-Hispanic
51 blacks (from 6.2% to 20.6%, *P* for trend < 0.001). Adults aged ≥ 80 years old had the
52 highest prevalence.

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

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

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3 57 **Strengths and limitations of this study**
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- 5 58 • We used the longitudinal data from nationally representative population-based surveys of
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8 59 the NHANES (1999-2006).
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10 60 • Body composition were measured by the golden standard of dual energy X-ray
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12 61 absorptiometry.
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14 62 • Appendicular skeletal muscle mass rather than muscle strength and physical performance
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17 63 was assessed.
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19 64 • The prevalence of pre-sarcopenia in women may be underestimated when used a height
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21 65 adjusted definition of pre-sarcopenia.
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24 66 • Reporting bias may exist due to self-reported physical activity data.
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71 INTRODUCTION

72 According to the 2010 European Working Group on Sarcopenia in Older People
73 (EWGSOP), sarcopenia is defined as a cluster of geriatric conditions characterized by
74 progressive and generalized loss of skeletal muscle mass and strength with a high risk of
75 adverse outcomes including poor quality of life, physical disability, and even death.[1] The
76 prevalence of pre-sarcopenia (52.7% in men and 25.3% in female) and sarcopenia (20.7% in
77 men and 15.3% in female) among adults aged 55 years and older are high, affecting about 30-
78 40% of those in long-term care.[2] It has been conservatively estimated that sarcopenia affects
79 more than 50 million people around the world and will increase by more than 200 million over
80 the next 40 years.[3]

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

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

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3 96 Therefore, it is reasonable to hypothesize that the prevalence of pre-sarcopenia has increased
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5 97 accordingly. Currently, there is a lack of evidence to support this statement. Numerous studies
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8 98 have confirmed that sarcopenia increases the risk of frailty,[12] inflammation ,[13 14] liver
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10 99 fibrosis,[15 16] cirrhosis,[17 18] systemic sclerosis,[19] cancer,[20-22] chronic obstructive
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12 100 pulmonary disease,[23] cardiovascular disease (CVD),[24 25] and mortality,[26] all of which
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14 101 place considerable health and economic burden on public health care services. Thus, it is
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16 102 important to depict the prevalence and trends of pre-sarcopenia and related body compositions
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18 103 over time in relation to sex, age, and race to better inform public health policy and prevention
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20 104 strategies.

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24 105 In this study, we estimated the population-based prevalence and temporal trends of pre-
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26 106 sarcopenia metrics and related body compositions among adults in the United States (U.S.)
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28 107 from 1999 to 2006 using data from the National Health and Nutrition Examination Survey
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30 108 (NHANES).

31 109 32 33 34 35 110 **METHODS**

36 37 111 **Study design and participants**

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39 112 The NHANES is a nationally representative cross-sectional survey among civilian non-
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41 113 institutionalized persons in the U.S..[27] This analytical study involved participants aged 18
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43 114 years and older from the NHANES cohort of four consecutive cycles: 1999-2000 ($n=3,559$),
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45 115 2001-2002 ($n=4,047$), 2003-2004 ($n=3,771$), and 2005-2006 ($n=3,071$). All NHANES
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47 116 protocols were approved by the National Center for Health Statistics Research ethics review
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49 117 board. All participants provided written informed consent.

50 51 118 **Body component measurements and pre-sarcopenia**

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53 119 Physical examinations were conducted in mobile examination centers. Weight in
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55 120 kilograms, height in centimeters, and waist circumference (WC) in centimeters were measured

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3 121 using standardized techniques and equipment. Body mass index (BMI) was calculated as
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5 122 weight in kilograms divided by height in meters squared. Overweight was defined as a BMI
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7 123 between 25.0-29.9 and obesity as a BMI of 30.0 or higher.[28] Central obesity was defined as
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9 124 having a WC of > 102 cm for males and > 88 cm for females.[29] Total body fat percentage,
10 125 total body fat mass, total lean body mass, appendicular skeletal muscle mass (ASM) and bone
11 126 mineral density (BMD) were measured using the dual energy X-ray absorptiometry (DXA) in
12 127 the four surveys from 1999 to 2006. Skeletal muscle mass index (SMI) was calculated as ASM
13 128 divided by height squared (kg/m^2). Pre-sarcopenia was sex-specifically defined as having a
14 129 $\text{SMI} \leq 7.26 \text{ kg/m}^2$ in men and $\leq 5.5 \text{ kg/m}^2$ in women.[30]

130 **Cardiovascular fitness**

131 Cardiovascular fitness was examined using treadmill test. Participants were assigned to
132 one of eight protocols, according to their gender, age, BMI, and self-reported levels of physical
133 activity. Each protocol included a 2-minute warm-up, two 3-minute exercise stages, and a 2-
134 minute cool-down period [31]. The goal of each protocol was to elicit a heart rate that was
135 approximately 80% of the age-predicted maximum ($220 - \text{age}$) by the end of the second exercise
136 stage. The heart rate was monitored continuously via 4 electrodes connected to the trunk and
137 abdomen of the participant, and it was recorded at the end of warm-up, each exercise stage,
138 and each minute of recovery. VO_2max (mL/kg/minute) was estimated by extrapolation to an
139 expected age-specific maximal heart rate by using measured heart rate responses to the two 3-
140 minute exercise stages [32, 33].

141 **Physical activity and social-demographic factors**

142 Participants' sex, age, race, education level, annual household income, time spent
143 watching television per day, and level of physical activity were collected by household
144 interviews. Age was grouped into three categories: 18 to 39 years old, 40 to 59 years old, and
145 60 years or older. Race was classified as non-Hispanic white, non-Hispanic black, Mexican

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3 146 American, and others. Educational level was categorized into < high school graduate, high
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5 147 school graduate/general equivalency diploma, or \geq college. Time spent watching TV per day
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7 148 was grouped into < 2h, 2–4h, or > 4h. Annual household income was grouped into < \$25000,
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9 \$25000 to \$55000, or > \$55000. Physical activity was grouped into two levels:
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11 moderate/below, or vigorous.
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151 **Statistical analyses**

152 Participants' characteristics, including sex, age, race, education level, annual household
153 income, time spent watching TV per day and level of physical activity, were shown as
154 unweighted frequency and weighted percentage with 95% confidence interval. Weighted
155 mean and corresponding 95% confidence intervals of body weight, BMI and obesity, WC and
156 central obesity, total body fat percentage, total lean body mass, ASM, SMI, BMD were
157 calculated, and mean changes with 95% confidence intervals (CI) of all these variables from
158 1999-2000 to 2005-2006 were calculated.

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

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

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3 170 windows version 9.4 (SAS Institute, Cary, NC, USA). A two-sided $P < 0.05$ was considered
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5 171 as statistically significant.
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8 172 **Patient and public involvement**

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10 173 There was no patient or public involvement in this study.
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14 175 **RESULTS**

16
17 176 A total of 14,448 participants were included in this study, with 3,559 from 1999-2000,
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19 177 4,047 from 2001-2002, 3,771 from 2003-2004, and 3,071 from 2005-2006 (**Table 1**).
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21 178 Distribution of participants' characteristics in the four survey cycles were comparable. In 1999-
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23 179 2000, 49.6% were women, 19.5% were 60 years or older, and 71.7% were Non-Hispanic white.
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25 180 The proportion of those with a vigorous physical activity level showed a significantly decreased
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27 181 trend from 1999 to 2006 ($p < 0.001$).
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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]				
18 – 39 yrs	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]
40 – 59 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]
60– 79yrs	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]
≥ 80 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]
	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 h	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]
2-4 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]
> 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]
	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]

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

190 The overall age- and sex-adjusted prevalence of pre-sarcopenia ranged from 16.4% (95%
191 CI: 18.1%, 21.4%) in 1999-2000 to 14.8% (95% CI: 14.9%, 20.2%) in 2005-2006 (*P* for trend
192 = 0.78) (**Table 2**).

193 The age- and sex-adjusted prevalence of pre-sarcopenia in men decreased from 22.7% (95%
194 CI: 20.3%, 25.2%) in 1999-2000 to 12.3% (95% CI: 10.6%, 14.3%) in 2005-2006 (*P* for trend
195 = 0.36); while in women, the prevalence went from 20.0% in 1999-2000 to 17.7% in 2005-
196 2006 (*P* for trend = 0.20). Sex differences were the largest in 2005-2006, 12.3% for men vs.
197 17.7% for women (*P* < 0.001). There were also racial differences of pre-sarcopenia prevalence
198 as well as temporal trend. It significantly increased from 6.2% in 1999-2000 to 20.6% in 2005-
199 2006 among non-Hispanic blacks (*P* for trend < 0.001), but remained stable among non-
200 Hispanic whites (*P* for trend = 0.84) and Mexican Americans (*P* for trend = 0.54) from 1999
201 to 2006. Participants aged ≥ 80 years and 60 – 79 years had a significantly higher prevalence
202 of sarcopenia in the four survey cycles from 1999-2004 compared to those aged 18–39 years
203 old and 40–59 years old. In three survey cycles of 1999-2000, 2001-2002, and 2003-2004,
204 participants who had vigorous physical activity levels were more likely to have relatively lower
205 prevalence of pre-sarcopenia compared to the lowest categories (*p* values < 0.01). In addition,
206 participants with higher family annual income had a lower prevalence of pre-sarcopenia in
207 survey cycles of 2001-2002 and 2003-2004. In all four survey cycles, participants with BMI <
208 25 kg/m² has a relatively higher prevalence of pre-sarcopenia as compare with overweight and
209 obese participants.

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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

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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/m²)	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/m²)	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/m²)	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	

211 Pre-sarcopenia was defined according to dual energy X-ray absorptiometry (DXA) criteria; GED, general equivalency diploma.
 212 #: P-trend (1999-2006): adjusted for sex, age, race, education level, family annual income, watch TV time per day, and physical activity level in
 213 logistic regression models.

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214 **Body Compositions**

215 The average bodyweight across all participants significantly increased from 76.8 kg (95%
216 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),
217 with an average increase of 2.11 kg (95%CI: 0.28, 3.93 kg) (**Table 3**). Correspondingly, the
218 prevalence of obesity significantly increased from 24.3% (95%CI: 21.2%, 27.4) to 29.3%
219 (95%CI: 25.8%, 32.7%) in the overall population (P for trend = 0.023), and from 20.8% (95%
220 CI: 17.9%, 23.7%) to 27.6% (95% CI: 23.0%, 32.1%) in men (P for trend=0.007), but remained
221 stable in women over time (from 28.0% to 30.9%, P for trend=0.229) (**Table 3 and Figure**
222 **1A**). After stratification by age (**Figure 1B**), obesity prevalence significantly increased from
223 25.6% to 33.8% in the 40-59 age group (P for trend=0.027), but remained stable in the other
224 three age groups. Similar increased trends of obesity prevalence were observed in non-Hispanic
225 whites (from 23.8% to 28.6%, P for trend =0.025) and others ethnical group (from 21.5% to
226 36.9%, P for trend =0.007), but were statistically stable in non-Hispanic blacks and Mexican
227 Americans (**Figure 1C**). And from 1999 to 2006, SMI was significantly decreased in non-
228 Hispanic black group, while it was significantly increased in Mexican American and others
229 ethnical groups (**Table 3 and Figure 2A**). Meanwhile, we observed a slight increase in waist
230 circumference (Table 3 and Figure 2B), total lean body mass (Table 3), prevalence of central
231 obesity (Table 3), and BMD (**Table 3 and Figure 2C**).

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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/m ²	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/m ²	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/cm ²	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 ₂ max, 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, VO₂max 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.

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3 244 **DISCUSSION**
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5 245 Using nearly 20 years of nationally representative U.S. data from NHANES, we found
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8 246 the overall prevalence of pre-sarcopenia remained stable between 1999 and 2006. However,
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10 247 stratification analyses revealed that pre-sarcopenia increased considerably among non-
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12 248 Hispanic blacks from 1999 to 2006. Obesity and central obesity significantly increased from
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14 249 1999 to 2006. As anticipated, pre-sarcopenia and its metrics increased accordingly in young
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17 250 people.

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19 251 Sarcopenia and obesity have common environmental risk factors, including over-
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21 252 nutrition, metabolic disorders, and a sedentary lifestyle.[34] Obesity can lead directly to loss
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23 253 of muscle mass and strength,[35] and is commonly accompanied with a reduction in physical
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25 254 activity and the promotion of metabolic disorders, which in turn, accelerates abnormal
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27 255 distribution of fat mass and initiates the process of sarcopenia.[36] Our study reveals an
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29 256 increasing trend in obesity prevalence across all three age groups. A significant elevation in
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31 257 the prevalence of pre-sarcopenia from 1999 to 2006 was observed in the young (18-39 years)
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33 258 age group. The peak period of skeletal muscle mass is around 20 years old which begins to
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35 259 decrease at around 30 years old.[37] The peak period of muscle strength lags nearly 10-years
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37 260 behind the peak period of muscle mass and starts to decline at around 50 years old.[38] The
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39 261 speed of declination of muscle strength is 2 to 5 times faster than that of muscle mass over
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41 262 the same period of time.[39] However, it is still unclear whether muscle mass reduction at a
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43 263 young age would further accelerate muscle strength loss and ageing related health issues.
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45 264 Observational studies reported a linearly positive association between muscle mass and
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47 265 strength in both middle aged and elderly people.[40-42] This indicates the higher the amount
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49 266 of muscle mass acquired during a young age may protect adults from the early onset of
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51 267 sarcopenia. Therefore, it may be beneficial for prevention and intervention strategies to pay
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53 268 more attention to increasing muscle mass in both young and old populations.
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3 269 We did not observe significant sex differences over time in relation to pre-sarcopenia
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5 270 prevalence. From 1999 to 2006, pre-sarcopenia prevalence remained stable in both men and
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7 271 women. Previous evidence is controversial and inconsistent. Michele *et al.* compared 195
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9 272 women aged 64 to 93 years old and 142 men aged 64 to 92 years old, they found a higher
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11 273 prevalence of sarcopenia in men than in women;[43] while in the Fifth Korea National Health
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13 274 and Nutrition Examination Survey, sarcopenia was more prevalent in women.[44] Women
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15 275 have less absolute and relative muscle mass than men[45] in biology. Besides natural
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17 276 differences in skeletal muscle between men and women, such as the amount of muscle mass,
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19 277 muscle capillary density, and muscle fiber type,[46] physical activity might be a potential
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21 278 cause for sex differences in sarcopenia prevalence.[47] In our study, most women had lower
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23 279 self-reported levels of physical activity than men. The amount of physical activity in men
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25 280 gradually increased, whereas it decreased in women over time. Another critical factor is age-
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27 281 related changes in the gonadal function and sex hormones regulating muscle mass
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29 282 distribution. Evidence suggested lower serum testosterone levels in elderly men contributes to
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31 283 muscle weakness.[48] Men experience a gradual decrease in knee extensor and handgrip
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33 284 strength between 20 and 80 years of age, whereas, women experience a steep decline after the
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35 285 age of 55 (menopausal age).[49 50] Although it is not clear whether age-related changes in
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37 286 the gonadal function directly regulate physical activity in humans, animals after gonadectomy
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39 287 can cause a dramatical decline in spontaneous physical activity.[51] Thus, sex differences
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41 288 might be pivotal in understanding the process of sarcopenia and aging, understanding why
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43 289 each sex remains “muscle healthy” throughout their lifespan could open new avenues to
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45 290 prevent and treat sarcopenia and the ageing process.

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54 291 We also detected a considerably increased trend of pre-sarcopenia prevalence in non-
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56 292 Hispanic black people, while the prevalence was stable in non-Hispanic Whites, Mexican
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58 293 Americans and other racial groups over time. Racial differences in muscle mass have been
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3 294 reported in previous studies. Evidence has shown African-Americans have significantly
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5 295 higher skeletal muscle/adipose tissue-free body mass ratio than other races, although the
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7 296 difference was very small.[52] Mahbubur and Abbey reported black women had greater
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9 297 levels of total and regional lean mass than White and Hispanic women, while Hispanic
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11 298 women had even lower values than white women after assessment of body composition of
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13 299 708 healthy black, white, and Hispanic women aged 16–33 years using DXA analysis.[53]
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15 300 According to the NHANES III bioelectrical impedance data, the amount of fat-free mass in
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17 301 Mexican-Americans was lower than in non-Hispanic Blacks, which was lower than in non-
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19 302 Hispanic Whites.[54] The underlying mechanism of racial differences is still unclear and
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21 303 warrants further investigation.
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26 304 This is a representative population-based study. This study firstly focused on the pre-
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28 305 sarcopenia among adults. Also, there are several limitations of this study. First, we only
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30 306 accessed muscle mass data rather than muscle strength which does not reflect muscle power
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32 307 and may be confounded by a third variable that was not involved in this study. Second, the
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34 308 prevalence of pre-sarcopenia in women may be underestimated because we used a height
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36 309 adjusted definition of pre-sarcopenia[55] which is potentially problematic in identifying
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38 310 participants with sarcopenic obesity.[56] However, if we had used the weight-adjusted
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40 311 definition, people classified as having sarcopenia would have had higher BMI values
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42 312 compared with those without sarcopenia.[57] Third, as physical activity data was self-
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44 313 reported, reporting bias may exist. Recent research on self-reported levels of physical activity
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46 314 indicated individuals in the U.S. tended to have differing perceptions of activity levels,
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48 315 overestimating their time spent exercising compared to Europeans.[58] Future studies should
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50 316 apply objective measures to muscle strength and physical activity to accurately evaluate
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52 317 sarcopenia prevalence.
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3 319 **CONCLUSIONS**
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5 320 Using data from the representative NHANES surveys covering nearly 20 years of data
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8 321 from 1999 to 2006, there was a youth tendency on prevalence of pre-sarcopenia from 1999 to
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10 322 2006 among U.S. adults. Pre-sarcopenia prevalence remains stable in both men and women
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12 323 over time. Together with an increase in obesity and central obesity, elevations of pre-
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14 324 sarcopenia in non-Hispanic blacks and young people were observed. It is recommended to
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16 325 control body fat ratio and develop good habit of keeping resistant and moderate physical
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18 326 activity to prevent sarcopenia both for young and elderly people. The continued high
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20 327 prevalence of pre-sarcopenia and obesity is an important public health concern.
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16
17
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28
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34 356 **Patient consent for publication**
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48 362 ethics review board.
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51 363 **Data availability statement**
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54 364 The data link is <https://www.cdc.gov/nchs/nhanes/index.htm>.
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3 520 **Figure Legends**
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6 521 **Figure 1.** Prevalence of obesity stratified by sex (A), age (B) and racial groups (C) from 1999
7 522 to 2006 in the NHANES surveys. 95% CI: 95% confidence interval. P values refer to
8 523 temporal trend by logistic regression models.
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11 524 **Figure 2.** Distribution of body compositions, including SMI (A), WC (B), BMD (C), and
12 525 TPF (D) by sex, age and racial groups from 1999 to 2006. SMI: Skeletal muscle index; WC:
13 526 Waist circumference; BMD: Bone mineral density; TPF: Total percentage of body fat; 95%
14 527 CI: 95% confidence interval. P values refer to temporal trend by logistic regression models.
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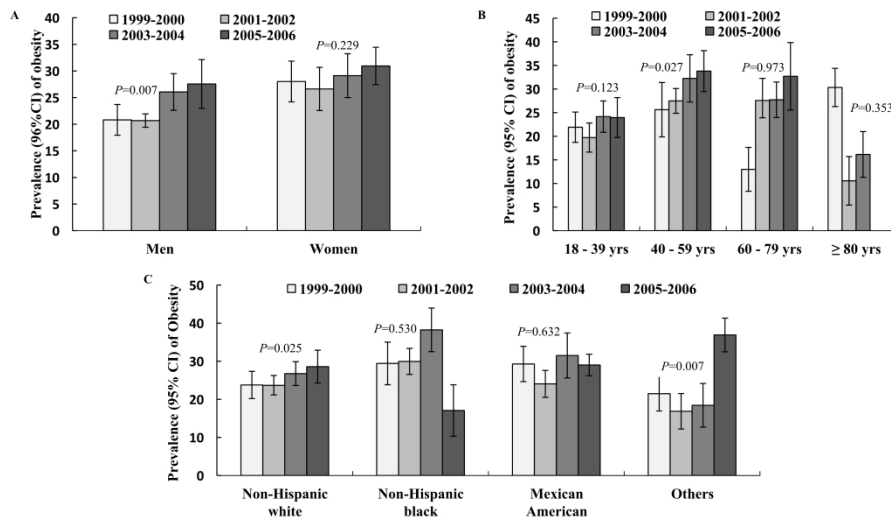


Figure 1. prevalence of obesity by gender, age and racial groups from 1999 to 2006

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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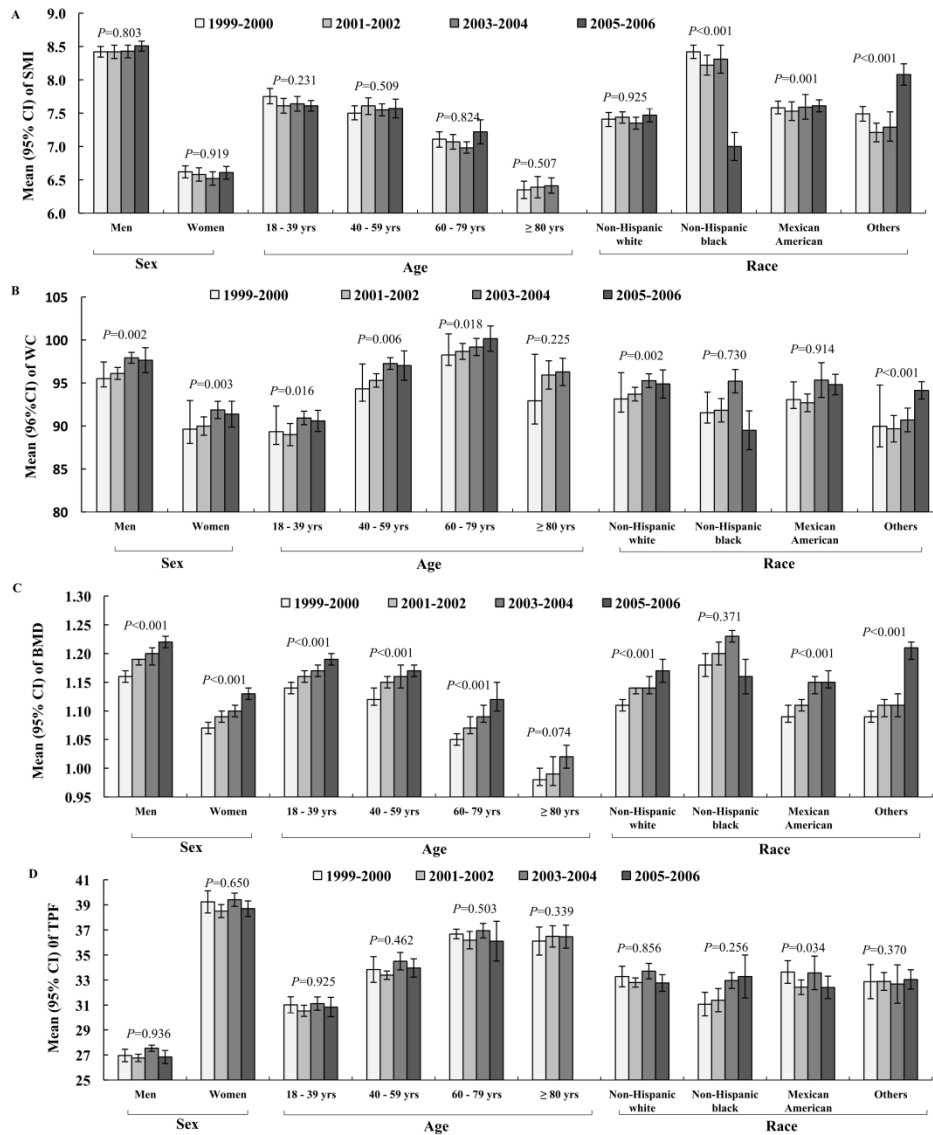


Figure 2. Distribution of body compositions, including SMI (A), WC (B), BMD (C), and TPF (D) by sex, age and racial groups from 1999 to 2006. SMI: Skeletal muscle index; WC: Waist circumference; BMD: Bone mineral density; TPF: Total percentage of body fat; 95% CI: 95% confidence interval. P values refer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

326x378mm (300 x 300 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: 6-8	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

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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
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*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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Keywords:	Body Composition, PUBLIC HEALTH, EPIDEMIOLOGY

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3 **1 Prevalence and Temporal Trends of Pre-sarcopenia Metrics and Related Body**
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5 **2 Composition Measurements from the 1999-2006 NHANES survey**
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9 **3** Ji-Bin Li ¹, Yu-Wan Wu ², Dan-Tong Gu ³, Hua-Jun Li ^{2*}, Xi Zhang ^{4*}
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31 **Word count:** 2827

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32 **Abstract**

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

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

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

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

43 **Outcome measures:** Pre-sarcopenia was sex-specifically defined as having a skeletal mass
44 index ≤ 7.26 kg/m² in men and ≤ 5.5 kg/m² in women. Body composition measurements,
45 including total body fat percentage, total body fat mass, total lean body mass, appendicular
46 skeletal muscle mass (ASM) and bone mineral density (BMD), were obtained by dual energy
47 X-ray absorptiometry.

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

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

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

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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.

72 INTRODUCTION

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

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

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

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3 97 Currently, there is a lack of evidence to support this statement. Numerous studies have reported
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5 98 that sarcopenia/low muscle mass is related to frailty, [12] inflammation, [13 14] liver fibrosis,
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8 99 [15 16] cirrhosis, [17 18] systemic sclerosis, [19] cancer, [20-22] chronic obstructive
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10 100 pulmonary disease, [23] cardiovascular disease (CVD), [24 25] and mortality, [26] all of which
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12 101 place considerable health and economic burdens on public health care services. Thus, it is
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14 102 important to depict the prevalence and temporal trends of pre-sarcopenia and related body
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16 103 composition measurements over time in relation to sex, age, and race to better inform public
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18 104 health policy and prevention strategies.

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21 105 In this study, we estimated the population-based prevalence and temporal trends of pre-
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23 106 sarcopenia metrics and related body composition measurements among adults in the United
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25 107 States (U.S.) from 1999 to 2006 by using data from the National Health and Nutrition
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27 108 Examination Survey (NHANES).

109 110 **METHODS**

111 **Study design and participants**

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

118 **Body component measurements and pre-sarcopenia**

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

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3 122 weight in kilograms divided by the square of the height in metres. Overweight was defined as
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5 123 a BMI between 25.0-29.9 and obesity as a BMI of 30.0 or higher. [28] Central obesity was
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7 124 defined as having a WC of > 102 cm for males and > 88 cm for females. [29] Total body fat
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9 125 percentage, total body fat mass, total lean body mass, appendicular skeletal muscle mass (ASM)
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11 126 and bone mineral density (BMD) were measured using dual energy X-ray absorptiometry
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13 127 (DXA) in the four surveys from 1999 to 2006. The total appendicular skeletal muscle mass
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15 128 index (TASM) was calculated as the ASM divided by the height squared (kg/m^2). Pre-
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17 129 sarcopenia was sex-specifically defined as having a TASM $\leq 7.26 \text{ kg}/\text{m}^2$ in men and ≤ 5.5
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19 130 kg/m^2 in women. [30]

131 **Physical activity and social-demographic factors**

132 Participants' sex, age, race, education level, annual household income, time spent
133 watching television per day, and level of physical activity were collected by household
134 interviews. Age was grouped into three categories: 18 to 39 years old, 40 to 59 years old, and
135 60 years or older. Race was classified as non-Hispanic white, non-Hispanic black, Mexican
136 American, and others. Educational level was categorized into < high school graduate, high
137 school graduate/general equivalency diploma, or \geq college. Time spent watching TV per day
138 was grouped into < 2 h, 2-4 h, or > 4 h. Annual household income was grouped into <
139 \$25000, \$25000 to \$55000, or > \$55000. Physical activity was grouped into two levels:
140 moderate/below or vigorous.

141 **Statistical analyses**

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

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3 146 and central obesity, total body fat percentage, total lean body mass, ASM, TASM, and BMD
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5 147 were calculated, and mean changes with 95% confidence intervals (CIs) of all these variables
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8 148 from 1999-2000 to 2005-2006 were calculated.

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10 149 The age- and sex-adjusted prevalence of pre-sarcopenia was calculated for the four
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12 150 survey cycles from 1999-2000 to 2005-2006 for the overall sample and the sex, age, race,
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14 151 education level, annual household income, time spent watching TV per day, and physical
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16 152 activity level subgroups. The temporal trends of pre-sarcopenia prevalence, obesity and
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18 153 different body composition measurements, including TASM, WC, BMD, and TPF, for the
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20 154 overall sample and within the subgroups were assessed by survey-weighted linear (for
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22 155 continuous outcomes) or logistic (for binary outcomes) regression models with survey year as
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24 156 a continuous (ordered categorical) independent variable after adjustment for sex, age, race,
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26 157 education level, annual household income, time spent watching TV per day, and physical
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28 158 activity level [31 32].

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33 159 Sampling weights were used to account for unequal probabilities of selection and
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35 160 nonresponses for all analyses, thereby providing estimates representative of the non-
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37 161 institutionalized civilian U.S. population. All statistical analyses were performed using SAS
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39 162 for Windows version 9.4 (SAS Institute, Cary, NC, USA). A two-sided $P < 0.05$ was
40
41 163 considered statistically significant.

42 164 **Patient and public involvement**

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44
45 165 There was no patient or public involvement in this study.

46 47 48 49 50 51 167 **RESULTS**

52
53 168 A total of 14,448 participants were included in this study, with 3,559 from 1999-2000,
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55 169 4,047 from 2001-2002, 3,771 from 2003-2004, and 3,071 from 2005-2006 (**Table 1**). The
56
57 170 distributions of the participants' characteristics across the four survey cycles were comparable.

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3 171 In 1999-2000, 49.6% of the participants were women, 19.5% were 60 years or older, and 71.7%
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5 172 were non-Hispanic white. The proportion of patients with a vigorous physical activity level
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8 173 showed a significantly decreasing trend from 1999 to 2006 ($P < 0.001$).
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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]				
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 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]

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

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

180 The age-adjusted prevalence of pre-sarcopenia in men was 22.7% (95% CI: 20.3%, 25.2%)
181 in 1999-2000 and 12.3% (95% CI: 10.6%, 14.3%) in 2005-2006 (*P* for trend = 0.36), while in
182 women, the prevalence was 20.0% in 1999-2000 and 17.7% in 2005-2006 (*P* for trend = 0.20).
183 The prevalence of pre-sarcopenia in women was significantly higher than that in men in 2005-
184 2006 (17.7% for women vs. 12.3% for men; *P* < 0.001). There were also racial differences in
185 pre-sarcopenia prevalence as well as temporal trends. The prevalence significantly increased
186 from 6.2% in 1999-2000 to 20.6% in 2005-2006 among non-Hispanic blacks (*P* for trend <
187 0.001) but remained stable among non-Hispanic whites (*P* for trend = 0.84) and Mexican
188 Americans (*P* for trend = 0.54) from 1999 to 2006. Compared to those in the other age groups,
189 participants aged ≥ 80 years and 60 – 79 years had a significantly higher prevalence of pre-
190 sarcopenia in the four survey cycles from 1999-2006. In three of the survey cycles (1999-2000,
191 2001-2002, and 2003-2004), compared to those who reported moderate/low physical activity
192 levels, participants who reported vigorous physical activity levels were more likely to have a
193 lower prevalence of pre-sarcopenia (*P* values < 0.01). In addition, participants with higher
194 annual household incomes had a lower prevalence of pre-sarcopenia in the 2001-2002 and
195 2003-2004 survey cycles. In all four survey cycles, participants with BMI < 25 kg/m² had a
196 relatively higher prevalence of pre-sarcopenia than overweight and obese participants.

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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					

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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/m²)	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/m²)	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/m²)	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	

198 --: Not available.

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

200 #: P-value for trend (1999-2006) was calculated by using logistic regression models adjusted for sex, age, race, education level, annual household income,

201 time spent watching TV per day, and physical activity level.

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

203 **Body Composition Measurements**

204 The average body weight across all participants significantly increased from 76.8 kg (95%
205 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),
206 with an average increase of 2.11 kg (95% CI: 0.28, 3.93 kg) (**Table 3**). Correspondingly, the
207 prevalence of obesity significantly increased from 24.3% (95% CI: 21.2%, 27.4%) to 29.3%
208 (95% CI: 25.8%, 32.7%) in the overall population (P for trend = 0.023) and from 20.8% (95%
209 CI: 17.9%, 23.7%) to 27.6% (95% CI: 23.0%, 32.1%) in men (P for trend=0.007) but remained
210 stable in women (from 28.0% to 30.9%, P for trend=0.229) over time (**Table 3 and Figure**
211 **1A**). After stratification by age (**Figure 1B**), the prevalence of obesity significantly increased
212 from 25.6% to 33.8% in the 40-59 age group (P for trend=0.027) but remained stable in the
213 other three age groups. Similar increasing trends of obesity prevalence were observed in non-
214 Hispanic whites (from 23.8% to 28.6%, P for trend =0.025) but were statistically stable in non-
215 Hispanic blacks and Mexican Americans (**Figure 1C**). From 1999 to 2006, the TASM
216 significantly decreased in the non-Hispanic black group but significantly increased in the
217 Mexican American and other ethnic groups (**Table 3 and Figure 2A**). Meanwhile, we observed
218 a slight increase in waist circumference (Table 3 and Figure 2B), total lean body mass (Table
219 3), prevalence of central obesity (Table 3), and BMD (**Table 3 and Figure 2C**).

224 **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/m ²	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/m ²	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/cm ²	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)

225 ASM: Appendicular skeletal muscle mass, TASM: Total appendicular skeletal muscle index, BMD: Bone mineral density;
 226 #: P-value for trend (1999-2006) was adjusted for sex, age, race, education level, annual household income, time spent watching TV per day, and
 227 physical activity level.
 228 All statistics were weighted and shown as the means (95% confidence interval) or † percentages (95% confidence intervals).

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3 231 **DISCUSSION**
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5 232 In this large-scale study that analysed nationally representative data from U.S.
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7 233 respondents to the NHANES, we found that the overall prevalence of pre-sarcopenia
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9 234 remained stable, while there was a substantial increase in the prevalence for the non-Hispanic
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11 235 black and young age groups from 1999 to 2006. Hence, our hypothesis regarding an
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13 236 increasing trend in the pre-sarcopenia prevalence over time was not fully supported by the
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15 237 findings. Our results indicate that certain subpopulations might be more vulnerable to pre-
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17 238 sarcopenia than the overall population. Indeed, we found that individuals who were older or
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19 239 under/normal weight had a considerably higher prevalence of pre-sarcopenia.
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24 240 Our study found an increasing trend in the prevalence of obesity and central obesity
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26 241 from 1999 to 2006 among the overall population. Previous studies reported that obesity can
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28 242 lead to loss of muscle mass and strength [33] and is commonly accompanied by a reduction
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30 243 in physical activity and deterioration of metabolic disorders, which in turn accelerates the
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32 244 abnormal distribution of fat mass and initiates the process of sarcopenia. [34] In contrast, it is
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34 245 interesting that the prevalence of pre-sarcopenia was considerably higher in under/normal
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36 246 weight adults than in obese adults in our study. The contradictory findings might be
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38 247 explained by the fact that our study only measured skeletal muscle mass, but the muscle mass
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40 248 of under/normal weight individuals might be relatively lower than that of overweight/obese
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42 249 individuals. In addition, our study focused on pre-sarcopenia rather than sarcopenia, which is
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44 250 defined as the presence of both low muscle mass and low muscle function (strength or
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46 251 physical performance).
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51 252 A previous study reported that skeletal muscle mass begins to decrease at approximately
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53 253 30 – 39 years old. [35] Accordingly, we found a relatively higher prevalence of pre-
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55 254 sarcopenia in the older age groups than in the 18-39 age group. However, it is still unclear
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57 255 whether muscle mass reduction would further accelerate muscle strength loss and ageing-
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3 256 related health issues. Observational studies have reported a linearly positive association
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5 257 between muscle mass and strength in both middle-aged and elderly people. [36-38] This
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7 258 indicates that the amount of muscle mass acquired during youth may protect adults from the
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9 259 early onset of sarcopenia. Therefore, it may be beneficial to pay more attention to increasing
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11 260 muscle mass in both young and old populations. The peak period of muscle strength lags
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13 261 nearly 10 years behind the peak period of muscle mass and starts to decline at approximately
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15 262 50 years of age. [39] The speed of muscle strength decline is 2 to 5 times faster than that of
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17 263 muscle mass over the same period.[40]
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21 264 We found that the prevalence of pre-sarcopenia was stable in both genders from 1999 to
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23 265 2006. It was also found that women had a higher prevalence of pre-sarcopenia than men in
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25 266 2005-2006. This might be caused by a more rapid decrease in the prevalence of pre-
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27 267 sarcopenia among men than women. Previous evidence, however, is inconsistent. For
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29 268 instance, the study of Michele *et al.* found a higher prevalence of sarcopenia in men than in
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31 269 women who were aged 64 to 93 years, [41] while the findings in the Fifth Korea National
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33 270 Health and Nutrition Examination Survey showed that sarcopenia was more prevalent in
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35 271 women. [42] Women have less absolute and relative muscle mass than men. [43] In addition,
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37 272 given the natural differences in skeletal muscle between men and women, such as the amount
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39 273 of muscle mass, muscle capillary density, and muscle fibre type, [44] physical activity might
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41 274 be a potential cause for sex differences in the prevalence of sarcopenia. [45] In our study,
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43 275 most women had lower self-reported levels of physical activity than men. Vigorous physical
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45 276 activity in men gradually increased, whereas it decreased in women over time. Another
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47 277 critical factor is age-related changes in gonadal function and sex hormones regulating muscle
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49 278 mass distribution. Evidence suggests that lower serum testosterone levels in elderly men
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51 279 contribute to muscle weakness. [46] Men experience a gradual decrease in knee extensor and
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53 280 handgrip strength between 20 and 80 years of age, whereas women experience a steep decline
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3 281 after the age of 55 (menopausal age). [47 48] Although it is not clear whether age-related
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5 282 changes in gonadal function directly regulate physical activity in humans, gonadectomy has
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8 283 been shown to cause a dramatic decline in spontaneous physical activity in animals. [49]
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10 284 Thus, sex differences might be pivotal in understanding the process of sarcopenia and ageing,
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12 285 and understanding why each sex remains “muscle healthy” throughout their lifespan could
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14 286 open new avenues to prevent sarcopenia and the ageing process.

17 287 We also detected a considerably increased trend of pre-sarcopenia prevalence in non-
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19 288 Hispanic black people, while the prevalence was stable in non-Hispanic whites and Mexican
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21 289 Americans over time. Racial differences in muscle mass have been reported in previous
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23 290 studies. Evidence has shown that African Americans have a significantly higher skeletal
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25 291 muscle/adipose tissue-free body mass ratio than other races, although the difference was very
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27 292 small. [50] Mahbubur and Abbey reported that black women had greater levels of total and
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29 293 regional lean mass than white and Hispanic women and that Hispanic women had even lower
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31 294 values than white women in an assessment of the body composition of 708 healthy black,
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33 295 white, and Hispanic women aged 16–33 years using DXA analysis. [51] According to the
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35 296 NHANES III bioelectrical impedance data, the amount of fat-free mass in Mexican
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37 297 Americans was lower than that in non-Hispanic Blacks, which was in turn lower than that in
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39 298 non-Hispanic Whites. [52] The underlying mechanism of these racial differences is still
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41 299 unclear and warrants further investigation.

46 300 This is a representative population-based study. This is the first study that focused on pre-
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48 301 sarcopenia among adults. However, there are several limitations in this study. First, we only
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50 302 assessed muscle mass data rather than muscle strength, which does not reflect muscle power
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52 303 and may be confounded by a third variable that was not involved in this study. Second, the
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54 304 prevalence of pre-sarcopenia in women may be underestimated because we used a height-
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56 305 adjusted definition of the condition, [53] which is potentially problematic in identifying
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3 306 participants with sarcopenic obesity. [54] However, if we had used the weight-adjusted
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5 307 definition, people classified as having pre-sarcopenia would have had higher BMI values
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8 308 compared with those without sarcopenia. [55] Third, as physical activity data were self-
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10 309 reported, reporting bias may exist. Recent research on self-reported levels of physical activity
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12 310 indicated that individuals in the U.S. tended to have differing perceptions of activity levels
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14 311 and that compared to Europeans, U.S. individuals overestimate their time spent exercising.
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16 312 [56] Future studies should apply objective measures to determine muscle strength and
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18 313 physical activity to accurately evaluate sarcopenia prevalence.
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23 315 **CONCLUSIONS**

26 316 The overall prevalence of pre-sarcopenia was stable in both men and women from 1999-
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28 317 2006 among U.S. adults, while there is a slight increase in the prevalence of pre-sarcopenia
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30 318 from 1999 to 2006 among U.S. young adults. Adults who were elderly or under/normal
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32 319 weight are at high-risk of pre-sarcopenia. Meanwhile, we found a significant increased trend
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34 320 of obesity, central obesity, and pre-sarcopenia in non-Hispanic blacks and young adults. It
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36 321 suggests that the high prevalence of pre-sarcopenia and obesity is an important public health
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38 322 concern. It might be helpful to maintain resistant and at least moderate physical activity for
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40 323 the prevention of sarcopenia and obesity in U.S. adults.
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10
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14
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18 337 authors took part in writing the manuscript and read and approved the final version.
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28

29 341 **Competing interests**
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32 342 None declared.
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34 343 **Patient consent for publication**
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36 344 Not required.
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46 348 All NHANES protocols were approved by the National Centre for Health Statistics Research
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48 349 ethics review board.
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51 350 **Data availability statement**
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54 351 The data link is <https://www.cdc.gov/nchs/nhanes/index.htm>.
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3 506 **Figure Legends**
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6 507 **Figure 1.** Prevalence of obesity stratified by sex (A), age (B) and racial group (C) from 1999
7 508 to 2006 in the NHANES surveys. 95% CI: 95% confidence interval. P values refer to
8 509 temporal trends obtained by logistic regression models after adjusting for sex, age, race,
9 510 education level, annual household income, time spent watching TV per day, and physical
10 511 activity level.
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15 512 **Figure 2.** Distribution of body composition measurements, including SMI (A), WC (B),
16 513 BMD (C), and TPF (D), by sex, age and racial group from 1999 to 2006. SMI: Skeletal
17 514 muscle index; WC: Waist circumference; BMD: Bone mineral density; TPF: Total percentage
18 515 of body fat; 95% CI: 95% confidence interval. P values refer to temporal trends obtained by
19 516 logistic regression models after adjusting for sex, age, race, education level, annual household
20 517 income, time spent watching TV per day, and physical activity level.
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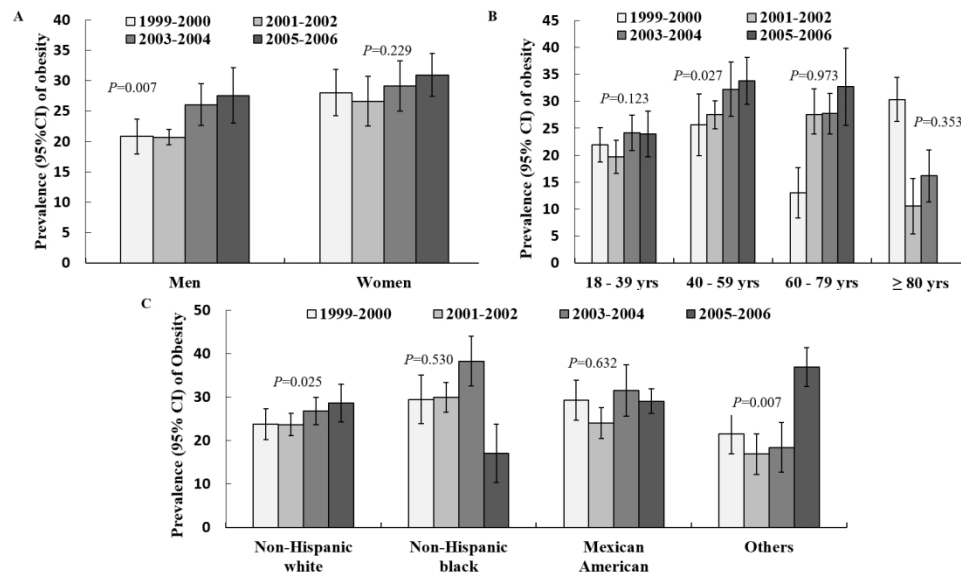


Figure 1. Prevalence of obesity stratified by sex (A), age (B) and racial group (C) from 1999 to 2006 in the NHANES surveys. 95% CI: 95% confidence interval. P values refer to temporal trends obtained by logistic regression models after adjusting for sex, age, race, education level, annual household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

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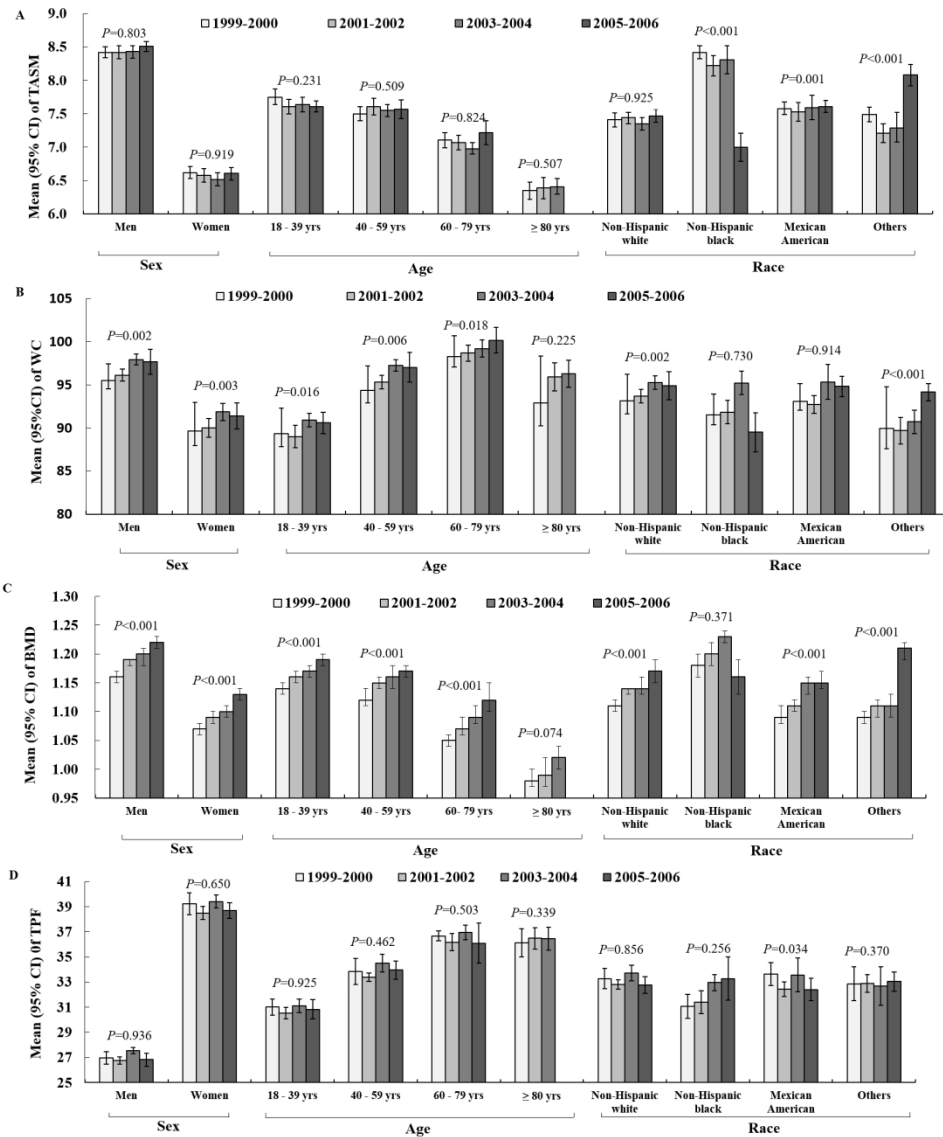


Figure 2. Distribution of body composition measurements, including SMI (A), WC (B), BMD (C), and TPF (D), by sex, age and racial group from 1999 to 2006. SMI: Skeletal muscle index; WC: Waist circumference; BMD: Bone mineral density; TPF: Total percentage of body fat; 95% CI: 95% confidence interval. 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.

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

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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
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*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.

BMJ Open

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

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3 **1 Prevalence and Temporal Trends of Pre-sarcopenia Metrics and Related Body**
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31 **Word count:** 2890

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32 **Abstract**

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

35 **Design:** Cross-sectional study.

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

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

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

43 **Outcome measures:** Pre-sarcopenia was sex-specifically defined as having a skeletal mass
44 index ≤ 7.26 kg/m² in men and ≤ 5.5 kg/m² in women. Body composition measurements,
45 including total body fat percentage, total body fat mass, total lean body mass, appendicular
46 skeletal muscle mass (ASM) and bone mineral density (BMD), were obtained by dual energy
47 X-ray absorptiometry.

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

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

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

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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.

72 INTRODUCTION

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

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

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

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3 97 Currently, there is a lack of evidence to support this statement. Numerous studies have reported
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5 98 that sarcopenia/low muscle mass is related to frailty, [12] inflammation, [13 14] liver fibrosis,
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8 99 [15 16] cirrhosis, [17 18] systemic sclerosis, [19] cancer, [20-22] chronic obstructive
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10 100 pulmonary disease, [23] cardiovascular disease (CVD), [24 25] and mortality, [26] all of which
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12 101 place considerable health and economic burdens on public health care services. Thus, it is
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14 102 important to depict the prevalence and temporal trends of pre-sarcopenia and related body
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16 103 composition measurements over time in relation to sex, age, and race to better inform public
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18 104 health policy and prevention strategies.

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21 105 In this study, we estimated the population-based prevalence and temporal trends of pre-
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23 106 sarcopenia metrics and related body composition measurements among adults in the United
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25 107 States (U.S.) from 1999 to 2006 by using data from the National Health and Nutrition
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27 108 Examination Survey (NHANES).

109 110 **METHODS**

111 **Study design and participants**

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

118 **Body component measurements and pre-sarcopenia**

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

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3 122 weight in kilograms divided by the square of the height in metres. Overweight was defined as
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5 123 a BMI between 25.0-29.9 and obesity as a BMI of 30.0 or higher. [28] Central obesity was
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7 124 defined as having a WC of > 102 cm for males and > 88 cm for females. [29] Total body fat
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9 125 percentage, total body fat mass, total lean body mass, appendicular skeletal muscle mass (ASM)
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11 126 and bone mineral density (BMD) were measured using dual energy X-ray absorptiometry
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13 127 (DXA) in the four surveys from 1999 to 2006. The total appendicular skeletal muscle mass
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15 128 index (TASM) was calculated as the ASM divided by the height squared (kg/m^2). Pre-
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17 129 sarcopenia was sex-specifically defined as having a TASM $\leq 7.26 \text{ kg}/\text{m}^2$ in men and ≤ 5.5
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19 130 kg/m^2 in women. [30]

131 **Physical activity and social-demographic factors**

132 Participants' sex, age, race, education level, annual household income, time spent
133 watching television per day, and level of physical activity were collected by household
134 interviews. Age was grouped into three categories: 18 to 39 years old, 40 to 59 years old, and
135 60 years or older. Race was classified as non-Hispanic white, non-Hispanic black, Mexican
136 American, and others. Educational level was categorized into < high school graduate, high
137 school graduate/general equivalency diploma, or \geq college. Time spent watching TV per day
138 was grouped into < 2 h, 2–4 h, or > 4 h. Annual household income was grouped into <
139 \$25000, \$25000 to \$55000, or > \$55000. Physical activity was grouped into two levels:
140 moderate/below or vigorous.

141 **Statistical analyses**

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

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3 146 and central obesity, total body fat percentage, total lean body mass, ASM, TASM, and BMD
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5 147 were calculated, and mean changes with 95% confidence intervals (CIs) of all these variables
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8 148 from 1999-2000 to 2005-2006 were calculated.

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10 149 The age- and sex-adjusted prevalence of pre-sarcopenia was calculated for the four
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12 150 survey cycles from 1999-2000 to 2005-2006 for the overall sample and the sex, age, race,
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14 151 education level, annual household income, time spent watching TV per day, and physical
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16 152 activity level subgroups. The temporal trends of pre-sarcopenia prevalence, obesity and
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18 153 different body composition measurements, including TASM, WC, BMD, and TPF, for the
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20 154 overall sample and within the subgroups were assessed by survey-weighted linear (for
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22 155 continuous outcomes) or logistic (for binary outcomes) regression models with survey year as
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24 156 a continuous (ordered categorical) independent variable after adjustment for sex, age, race,
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26 157 education level, annual household income, time spent watching TV per day, and physical
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28 158 activity level [31 32].

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33 159 Sampling weights were used to account for unequal probabilities of selection and
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35 160 nonresponses for all analyses, thereby providing estimates representative of the non-
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37 161 institutionalized civilian U.S. population. All statistical analyses were performed using SAS
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39 162 for Windows version 9.4 (SAS Institute, Cary, NC, USA). A two-sided $P < 0.05$ was
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41 163 considered statistically significant.

42 164 **Patient and public involvement**

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45 165 There was no patient or public involvement in this study.

46 47 48 49 50 51 167 **RESULTS**

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53 168 A total of 14,448 participants were included in this study, with 3,559 from 1999-2000,
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55 169 4,047 from 2001-2002, 3,771 from 2003-2004, and 3,071 from 2005-2006 (**Table 1**). The
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57 170 distributions of the participants' characteristics across the four survey cycles were comparable.

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3 171 In 1999-2000, 49.6% of the participants were women, 19.5% were 60 years or older, and 71.7%
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5 172 were non-Hispanic white. The proportion of patients with a vigorous physical activity level
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7 173 showed a significantly decreasing trend from 1999 to 2006 ($P < 0.001$).
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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]				
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 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]

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4	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]
5	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]
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176 **Prevalence and temporal trends of pre-sarcopenia from 1999 to 2006**

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

180 The age-adjusted prevalence of pre-sarcopenia in men was 22.7% (95% CI: 20.3%, 25.2%)
181 in 1999-2000 and 12.3% (95% CI: 10.6%, 14.3%) in 2005-2006 (*P* for trend = 0.36), while in
182 women, the prevalence was 20.0% in 1999-2000 and 17.7% in 2005-2006 (*P* for trend = 0.20).
183 The prevalence of pre-sarcopenia in women was significantly higher than that in men in 2005-
184 2006 (17.7% for women vs. 12.3% for men; *P* < 0.001). There were also racial differences in
185 pre-sarcopenia prevalence as well as temporal trends. The prevalence significantly increased
186 from 6.2% in 1999-2000 to 20.6% in 2005-2006 among non-Hispanic blacks (*P* for trend <
187 0.001) but remained stable among non-Hispanic whites (*P* for trend = 0.84) and Mexican
188 Americans (*P* for trend = 0.54) from 1999 to 2006. Compared to those in the other age groups,
189 participants aged ≥ 80 years and 60 – 79 years had a significantly higher prevalence of pre-
190 sarcopenia in the four survey cycles from 1999-2006. In three of the survey cycles (1999-2000,
191 2001-2002, and 2003-2004), compared to those who reported moderate/low physical activity
192 levels, participants who reported vigorous physical activity levels were more likely to have a
193 lower prevalence of pre-sarcopenia (*P* values < 0.01). In addition, participants with higher
194 annual household incomes had a lower prevalence of pre-sarcopenia in the 2001-2002 and
195 2003-2004 survey cycles. In all four survey cycles, participants with BMI < 25 kg/m² had a
196 relatively higher prevalence of pre-sarcopenia than overweight and obese participants.

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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					

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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/m²)	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/m²)	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/m²)	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	

198 --: Not available.

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

200 #: P-value for trend (1999-2006) was calculated by using logistic regression models adjusted for sex, age, race, education level, annual household income,

201 time spent watching TV per day, and physical activity level.

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

203 **Body Composition Measurements**

204 The average body weight across all participants significantly increased from 76.8 kg (95%
205 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),
206 with an average increase of 2.11 kg (95% CI: 0.28, 3.93 kg) (**Table 3**). Correspondingly, the
207 prevalence of obesity significantly increased from 24.3% (95% CI: 21.2%, 27.4%) to 29.3%
208 (95% CI: 25.8%, 32.7%) in the overall population (P for trend = 0.023) and from 20.8% (95%
209 CI: 17.9%, 23.7%) to 27.6% (95% CI: 23.0%, 32.1%) in men (P for trend=0.007) but remained
210 stable in women (from 28.0% to 30.9%, P for trend=0.229) over time (**Table 3 and Figure**
211 **1A**). After stratification by age (**Figure 1B**), the prevalence of obesity significantly increased
212 from 25.6% to 33.8% in the 40-59 age group (P for trend=0.027) but remained stable in the
213 other three age groups. Similar increasing trends of obesity prevalence were observed in non-
214 Hispanic whites (from 23.8% to 28.6%, P for trend =0.025) but were statistically stable in non-
215 Hispanic blacks and Mexican Americans (**Figure 1C**). From 1999 to 2006, the TASM
216 significantly decreased in the non-Hispanic black group but significantly increased in the
217 Mexican American and other ethnic groups (**Table 3 and Figure 2A**). Meanwhile, we observed
218 a slight increase in waist circumference (**Table 3 and Figure 2B**), total lean body mass (**Table**
219 **3**), prevalence of central obesity (**Table 3**), and BMD (**Table 3 and Figure 2C**), however, we
220 did not detect any significant trends for TPF (**Figure 2D**).

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

Characteristics	Survey cycles				<i>P</i> -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/m ²	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/m ²	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/cm ²	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)

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

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

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

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3 232 **DISCUSSION**
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5 233 In this large-scale study that analysed nationally representative data from U.S.
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7 234 respondents to the NHANES, we found that the overall prevalence of pre-sarcopenia
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9 235 remained stable, while there was a substantial increase in the prevalence for the non-Hispanic
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11 236 black and young age groups from 1999 to 2006. Hence, our hypothesis regarding an
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13 237 increasing trend in the pre-sarcopenia prevalence over time was not fully supported by the
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15 238 findings. Our results indicate that certain subpopulations might be more vulnerable to pre-
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17 239 sarcopenia than the overall population. Indeed, we found that individuals who were older or
18
19 240 under/normal weight had a considerably higher prevalence of pre-sarcopenia.
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24 241 Our study found an increasing trend in the prevalence of obesity and central obesity
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26 242 from 1999 to 2006 among the overall population. Previous studies reported that obesity can
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28 243 lead to loss of muscle mass and strength [33] and is commonly accompanied by a reduction
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30 244 in physical activity and deterioration of metabolic disorders, which in turn accelerates the
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32 245 abnormal distribution of fat mass and initiates the process of sarcopenia. [34] In contrast, it is
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34 246 interesting that the prevalence of pre-sarcopenia was considerably higher in under/normal
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36 247 weight adults than in obese adults in our study. The contradictory findings might be
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38 248 explained by the fact that our study only measured skeletal muscle mass, but the muscle mass
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40 249 of under/normal weight individuals might be relatively lower than that of overweight/obese
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42 250 individuals. In addition, our study focused on pre-sarcopenia rather than sarcopenia, which is
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44 251 defined as the presence of both low muscle mass and low muscle function (strength or
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46 252 physical performance).
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51 253 A previous study reported that skeletal muscle mass begins to decrease at approximately
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53 254 30 – 39 years old. [35] Accordingly, we found a relatively higher prevalence of pre-
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55 255 sarcopenia in the older age groups than in the 18-39 age group. However, it is still unclear
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57 256 whether muscle mass reduction would further accelerate muscle strength loss and ageing-
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3 257 related health issues. Observational studies have reported a linearly positive association
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5 258 between muscle mass and strength in both middle-aged and elderly people. [36-38] This
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7 259 indicates that the amount of muscle mass acquired during youth may protect adults from the
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9 260 early onset of sarcopenia. Therefore, it may be beneficial to pay more attention to increasing
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11 261 muscle mass in both young and old populations. The peak period of muscle strength lags
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13 262 nearly 10 years behind the peak period of muscle mass and starts to decline at approximately
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15 263 50 years of age. [39] The speed of muscle strength decline is 2 to 5 times faster than that of
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17 264 muscle mass over the same period.[40]
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21 265 We found that the prevalence of pre-sarcopenia was stable in both genders from 1999 to
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23 266 2006. It was also found that women had a higher prevalence of pre-sarcopenia than men in
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25 267 2005-2006. This might be caused by a more rapid decrease in the prevalence of pre-
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27 268 sarcopenia among men than women. Previous evidence, however, is inconsistent. For
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29 269 instance, the study of Michele *et al.* found a higher prevalence of sarcopenia in men than in
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31 270 women who were aged 64 to 93 years, [41] while the findings in the Fifth Korea National
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33 271 Health and Nutrition Examination Survey showed that sarcopenia was more prevalent in
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35 272 women. [42] Women have less absolute and relative muscle mass than men. [43] In addition,
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37 273 given the natural differences in skeletal muscle between men and women, such as the amount
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39 274 of muscle mass, muscle capillary density, and muscle fibre type, [44] physical activity might
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41 275 be a potential cause for sex differences in the prevalence of sarcopenia. [45] In our study,
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43 276 most women had lower self-reported levels of physical activity than men. Vigorous physical
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45 277 activity in men gradually increased, whereas it decreased in women over time. Another
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47 278 critical factor is age-related changes in gonadal function and sex hormones regulating muscle
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49 279 mass distribution. Evidence suggests that lower serum testosterone levels in elderly men
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51 280 contribute to muscle weakness. [46] Men experience a gradual decrease in knee extensor and
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53 281 handgrip strength between 20 and 80 years of age, whereas women experience a steep decline
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3 282 after the age of 55 (menopausal age). [47 48] Although it is not clear whether age-related
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5 283 changes in gonadal function directly regulate physical activity in humans, gonadectomy has
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8 284 been shown to cause a dramatic decline in spontaneous physical activity in animals. [49]
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10 285 Thus, sex differences might be pivotal in understanding the process of sarcopenia and ageing,
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12 286 and understanding why each sex remains “muscle healthy” throughout their lifespan could
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15 287 open new avenues to prevent sarcopenia and the ageing process.

16
17 288 We also detected a considerably increased trend of pre-sarcopenia prevalence in non-
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19 289 Hispanic black people, while the prevalence was stable in non-Hispanic whites and Mexican
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22 290 Americans over time. Racial differences in muscle mass have been reported in previous
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24 291 studies. Evidence has shown that African Americans have a significantly higher skeletal
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26 292 muscle/adipose tissue-free body mass ratio than other races, although the difference was very
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28 293 small. [50] Mahbubur and Abbey reported that black women had greater levels of total and
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30 294 regional lean mass than white and Hispanic women and that Hispanic women had even lower
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33 295 values than white women in an assessment of the body composition of 708 healthy black,
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35 296 white, and Hispanic women aged 16–33 years using DXA analysis. [51] According to the
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37 297 NHANES III bioelectrical impedance data, the amount of fat-free mass in Mexican
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39 298 Americans was lower than that in non-Hispanic Blacks, which was in turn lower than that in
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42 299 non-Hispanic Whites. [52] The underlying mechanism of these racial differences is still
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45 300 unclear and warrants further investigation.

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47 301 This is a representative population-based study. This is the first study that focused on pre-
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49 302 sarcopenia among adults. However, there are several limitations in this study. First, we only
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51 303 assessed muscle mass data rather than muscle strength, which does not reflect muscle power
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54 304 and may be confounded by a third variable that was not involved in this study. Second, the
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56 305 prevalence of pre-sarcopenia in women may be underestimated because we used a height-
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58 306 adjusted definition of the condition, [53] which is potentially problematic in identifying
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3 307 participants with sarcopenic obesity. [54] However, if we had used the weight-adjusted
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5 308 definition, people classified as having pre-sarcopenia would have had higher BMI values
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8 309 compared with those without sarcopenia. [55] Third, as physical activity data were self-
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10 310 reported, reporting bias may exist. Recent research on self-reported levels of physical activity
11
12 311 indicated that individuals in the U.S. tended to have differing perceptions of activity levels
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14 312 and that compared to Europeans, U.S. individuals overestimate their time spent exercising.
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16
17 313 [56] Future studies should apply objective measures to determine muscle strength and
18
19 314 physical activity to accurately evaluate sarcopenia prevalence.
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23 316 **CONCLUSIONS**

26 317 The overall prevalence of pre-sarcopenia was stable in both men and women from 1999-
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28 318 2006 among U.S. adults, while there is a slight increase in the prevalence of pre-sarcopenia
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30 319 from 1999 to 2006 among U.S. young adults. Adults who were non-Hispanic blacks, elderly
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32 320 or under/normal weight are at high-risk of pre-sarcopenia. Meanwhile, we found a significant
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35 321 increased trend of obesity, central obesity. It suggests that the high prevalence of pre-
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37 322 sarcopenia and obesity is an important public health concern. It might be helpful to maintain
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40 323 resistant and at least moderate physical activity for the prevention of sarcopenia and obesity
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42 324 in U.S. adults.
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6
7
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10
11 335 **Contributors**
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13 336 JBL, XZ and HJL designed and conducted the research; JBL, XZ and HJL analysed the data;
14
15 337 JBL, XZ, HJL, YWW and DTG were responsible for the final content of the manuscript; all
16
17 338 authors took part in writing the manuscript and read and approved the final version.
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27
28

29 342 **Competing interests**
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31
32 343 None declared.
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34 344 **Patient consent for publication**
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36 345 Not required.
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38 346 **Provenance and peer review**
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41 347 Not commissioned; externally peer reviewed.
42

43 348 **Ethics approval**
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46 349 All NHANES protocols were approved by the National Centre for Health Statistics Research
47
48 350 ethics review board.
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51 351 **Data availability statement**
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54 352 The data link is <https://www.cdc.gov/nchs/nhanes/index.htm>.
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For peer review only

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3 507 **Figure Legends**
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5
6 508 **Figure 1.** Prevalence of obesity stratified by sex (A), age (B) and racial group (C) from 1999
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8 509 to 2006 in the NHANES surveys. 95% CI: 95% confidence interval. P values refer to
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10 510 temporal trends obtained by logistic regression models after adjusting for sex, age, race,
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12 511 education level, annual household income, time spent watching TV per day, and physical
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14 512 activity level.

15 513 **Figure 2.** Distribution of body composition measurements, including SMI (A), WC (B),
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17 514 BMD (C), and TPF (D), by sex, age and racial group from 1999 to 2006. SMI: Skeletal
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19 515 muscle index; WC: Waist circumference; BMD: Bone mineral density; TPF: Total percentage
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21 516 of body fat; 95% CI: 95% confidence interval. P values refer to temporal trends obtained by
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23 517 logistic regression models after adjusting for sex, age, race, education level, annual household
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25 518 income, time spent watching TV per day, and physical activity level.
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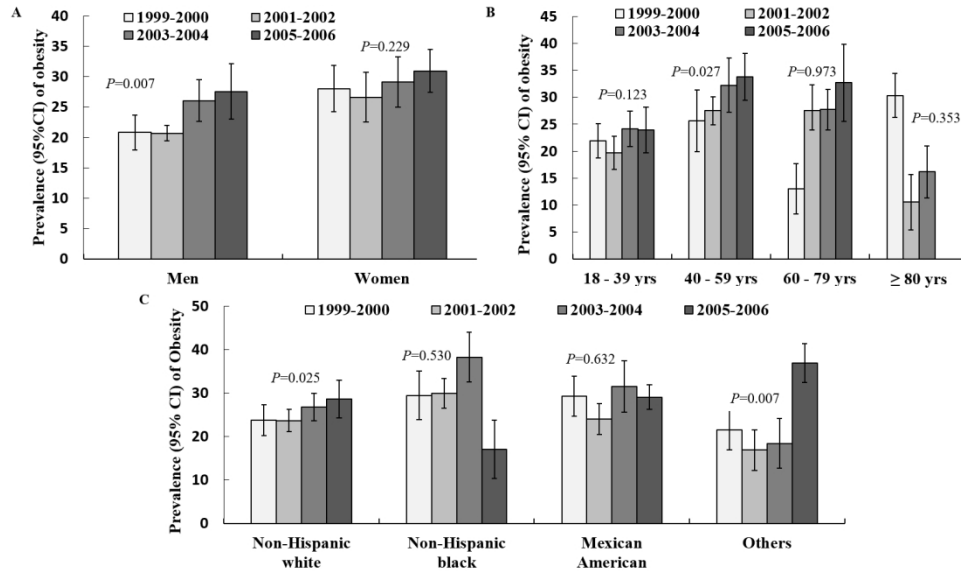


Figure 1. Prevalence of obesity stratified by sex (A), age (B) and racial group (C) from 1999 to 2006 in the NHANES surveys. 95% CI: 95% confidence interval. P values refer to temporal trends obtained by logistic regression models after adjusting for sex, age, race, education level, annual household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

296x182mm (150 x 150 DPI)

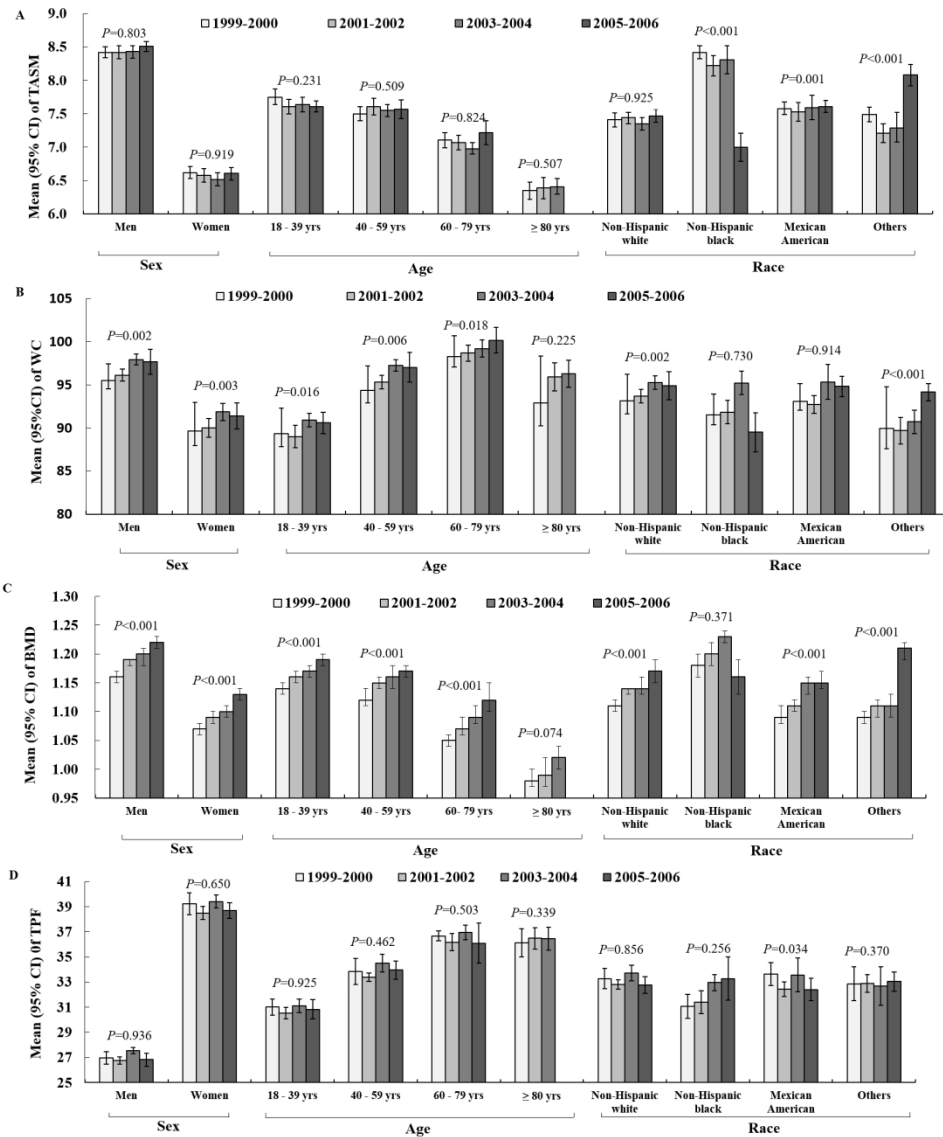


Figure 2. Distribution of body composition measurements, including SMI (A), WC (B), BMD (C), and TPF (D), by sex, age and racial group from 1999 to 2006. SMI: Skeletal muscle index; WC: Waist circumference; BMD: Bone mineral density; TPF: Total percentage of body fat; 95% CI: 95% confidence interval. 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.

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

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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
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*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.