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Secular trends for skinfolds differ from those for BMI and waist circumference among adults examined in NHANES from 1988–1994 through 2009–2010[1,,2,,3]

David S Freedman[4,*], **Babette S Zemel**[5], and **Cynthia L Ogden**[6]

[4]Division of Nutrition, Physical Activity and Obesity, CDC, Atlanta, GA

[5]Division of Gastroenterology, Hepatology and Nutrition, The Children's Hospital of Philadelphia, Philadelphia, PA

[6]National Center for Health Statistics, CDC, Hyattsville, MD

Abstract

Background—Although the prevalence of a body mass index [BMI (in kg/m^2)] ≥30 has tripled among US adults since the 1960s, BMI is only moderately correlated with body fatness. Because skinfolds can more accurately estimate body fatness than can BMI, it is possible that skinfolds could be useful in monitoring secular trends in body fatness.

Objective—We examined whether there were similar secular trends for skinfolds (triceps and subscapular), BMI, and waist circumference between US adults.

Design—This study was an analysis of 45,754 adults who participated in the NHANES from 1988–1994 through 2009–2010. Approximately 19% of the subjects were missing ≥1 skinfold-thickness measurement. These missing values were imputed from other characteristics.

Results—Trends in mean levels and in the prevalence of high levels of the 4 body size measures were fairly similar between men, with mean levels increasing by ≥5% from 1988–1994 through 2009–2010. Slightly larger increases were seen in women for BMI and waist circumference (7–8%), but trends in skinfolds were markedly different. The mean triceps skinfold, for example, increased by 2 mm through 2003–2004, but subsequently decreased so that the mean in 2009–2010 did not differ from that in 1988–1994. Compared with obese women in 1988–1994, the mean BMI of obese women in 2009–2010 was 1 higher, but mean levels of both skin-folds were 5–10% lower.

Conclusions—Although there were fairly similar trends in levels of BMI, waist circumference, and skinfold thicknesses in men in the United States from 1988–1994 through 2009–2010, there

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[2]The findings and conclusions in this report are those of the authors and do not necessarily represent the position of the CDC.

[3]Supplemental Figures 1 and 2 are available from the "Online Supporting Material" link in the online posting of the article and from the same link in the online table of contents at http://ajcn.nutrition.org.

[*]To whom correspondence should be addressed. 3.14david@gmail.com.

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were substantial differences in women. Our results indicate that it is unlikely that skinfold thicknesses could be used to monitor trends in obesity.

Keywords

BMI; NHANES; secular trends; skinfolds; waist circumference

INTRODUCTION

Mean levels of BMI and the prevalence of obesity, defined as a BMI (in kg/m^2) ≥30, have increased from ~13% to 38% in US adults since the 1960s (1–3). Because BMI can be an inaccurate indicator of body fatness (4), secular trends in other measures, such as the thickness of various skinfolds and waist circumference, have also been examined. The secular increases in waist circumference have been larger and somewhat independent of changes in BMI (5, 6), but fewer studies have examined trends in skinfolds. However, it has been reported (7) that the prevalence of a large skinfold (sum of triceps and subscapular) increased from 10% (1966–1980) to 26% (2005–2006) in US adults. Increases in the prevalence of large skinfold thicknesses (or increases in mean levels) have also been observed in children in the United States and in other countries (8, 9).

Despite the strong association between skinfold thicknesses and more accurate estimates of body fatness (10–12), it can be difficult to standardize these measurements, particularly in long-term studies in which measurements are made by different observers (13) and calipers (14, 15). For example, whereas skinfold measurements in national surveys conducted by the National Center for Health Statistics before 1988 were obtained with the use of Lange calipers, studies since then have been made with Holtain calipers that can lead to values that are up to 2–5 mm lower (16, 17). There have also been differences in the location of the waist circumference measurement across surveys (18, 19).

The objective of the current study was to contrast differences in the secular trends in skinfold thicknesses (triceps and subscapular) with those for BMI and waist circumference in US adults from 1988–1994 through 2009–2010. Similar protocols were used for the measurement of waist circumference and skinfolds over this time period.

METHODS

Sample

We used data from the NHANES III (1988–1994) and from six 2-y cycles conducted from 1999–2000 through 2009–2010 (20). Skinfold thicknesses were not measured in 2011–2012 and 2013–2014 NHANES cycles. The NHANES uses a multistage, stratified cluster design to select a representative sample of the US civilian, noninstitutionalized population. The surveys received human subjects' research approval, participants provided informed consent, and the procedures were in accord with the ethical standards of the CDC.

The current analyses included men and nonpregnant women who were ≥20 y of age at interview, and who had measurements of height and weight. A flowchart showing the selection of subjects for the current analyses can be found in **Supplemental** Figure 1. Race and Hispanic origin were self-reported; subjects in the current study were classified as non-Hispanic white, non-Hispanic black, Mexican American, or other (which included other Hispanics and multiracial persons).

Physical examination

During the physical examination, weight, height, waist circumference, and skinfolds (triceps and subscapular) were measured in a standardized fashion (19). BMI was calculated as weight divided by height (kg/m^2), and obesity was defined as a BMI ≥30. Waist circumference was measured to the nearest 1 mm just above the iliac crest with the use of a steel tape (19).

High levels of the skinfolds and waist circumference were defined so that the prevalence in the NHANES III within each sex and age group (20–39, 40–59, and ≥60 y) would equal the prevalence of BMI ≥30 within that group. For example, 25.3% of 20- to 39-y-old men in the NHANES III had a BMI ≥30, and for this sex-age group, a triceps skinfold ≥18.3 mm (the 74.7th percentile; 100% – 25.3%) was considered to be high. The sex- and age-specific cutoffs from the NHANES III were then applied to subsequent 2-y cycles to define high levels of waist circumference and skinfolds.

A relatively large number of adults in the various surveys were missing skinfold thickness measurements (21), with 19% (n = 8693) missing information on one or both skinfolds. Because these adults tended to have higher BMIs and waist circumferences than those with measured skinfolds (Table 1), an analysis of only nonmissing data would be biased. We therefore used a multiple imputation (22, 23) procedure to estimate values of the skinfolds and waist circumference from other characteristics, including sex, age, race, BMI, waist and arm circumferences, and dual-energy X-ray absorptiometry (DXA)–estimated fat mass (kilograms) in the 1999–2000 through 2005–2006 cycles (24, 25).

Statistical methods

All analyses accounted for the examination sample weights and sample design with the use of the survey package in R (26). All estimates of means and prevalences were age-standardized to the projected estimates of the 2000 US Census by the direct method, with the use of the age groups 20–39 y (39.7%), 40–59 y (37.2%), and ≥60 y (23.2%) (27). We used the aregImpute function in the Hmisc package of R (28) to generate the 5 sets of (multiple) imputations. To account for the uncertainty in these estimates, we analyzed each imputation set separately, and then combined the results over the 5 sets (29) in all analyses. Sensitivity analyses were performed in which we compared the multiple imputation results with those obtained in analyses that *1*) were restricted to subjects who had nonmissing skinfolds and *2*) recoded the skinfolds that exceeded the maximum capacity of the caliber to 50 mm (slightly greater than the maximum recorded value in 1988–1994 and 6–9 mm greater than the maximum values in subsequent cycles).

Because the analyses of high levels of the body size measures and the prevalence of missing data resulted in large SEs, we combined the 2-y cycles into 4-y groups when estimating prevalences. To assess the statistical significance of the observed trends, we used linear or Poisson regression (30, 31). The latter can directly estimate RRs, but because the estimated

CIs are conservative (32), we estimated SEs with the use of a quasi-Poisson model (30). All regression models were controlled for race and age (modeled with the use of cubic restricted splines).

In addition to focusing on secular trends in mean and high levels of the body size measures, we also examined whether trends in skinfold thicknesses varied by race, age, or BMI status [BMI <25 (normal weight), 25–29.9 (overweight), and ≥30 (obese)] by including various interaction terms in the regression models. Although there were statistically significant interactions between the skinfolds and all 3 variables, the strongest interaction was with BMI status. This interaction is shown graphically.

RESULTS

The number of subjects and various BMI percentiles by sex and examination period according to the availability of the triceps skinfold-thickness measurement is shown in Table 1. Approximately 6% of men were missing a triceps skinfold-thickness measurement, but the comparable percentage of missing data in women was higher (11%) and varied by examination period; ~18% of measurements were missing in women in 2003–2006 (the skinfold exceeded the capacity of the caliper for >7% of women in 2003–2006). Furthermore, the triceps skinfold measurements exceeded the capacity of the caliper >5 times as frequently in women (5% across all survey years) as in men (0.7%). Approximately 20% (men) to 25% (women) of subjects examined from 1999–2000 through 2009–2010 were missing information on one or both skinfolds.

The median BMIs of subjects in the 2 missing triceps skinfold categories were higher than in those who had a valid measurement (particularly in the "exceeded capacity" category), but there was substantial overlap in BMI levels. With the exception of 1988–1994, the 50th percentile of BMI among adults in the "could not obtain" category was fairly similar to the 90th percentile of those with a measured triceps skinfold level. Fairly similar patterns were seen for subscapular skinfold (data not shown), but a larger number of subjects were missing information for this skinfold.

Mean, age-standardized levels of the 4 body size measures by sex over the study period are shown in Figure 1 and Table 2. Values of waist circumference in Figure 1 have been divided by 4 to display on a similar scale as BMI and the skinfolds. Among men, there were fairly monotonic increases in each measure, and in 2009–2010, mean levels were 5% (waist circumference) to 14% (triceps skinfold) higher than those in 1988–1994. Among women, somewhat similar trends were observed for BMI and waist circumference, with mean levels being ~7–8% higher in 2009–2010 than in 1988–1994. However, skinfold trends were markedly different between men and women. Among women, the mean triceps skinfold increased by 1.6 mm through 2003–2004, but subsequently decreased by the same amount through 2009–2010. Although the subscapular skinfold increased between several cycles, it decreased by ~0.7 mm from 2007–2008 to 2009–2010. Among women, mean levels of the 2 skinfolds were either no higher (triceps) or 0.5 mm higher (subscapular) in 2009–2010 than in 1988–1994. As assessed in regression models that controlled for age and race, there were statistically significant ($P < 0.0001$) increases in BMI and waist circumference in both sexes.

The observed skinfold trends were also statistically significant at the 0.01 level in men [triceps—β: 1.1 cm/decade (0.9, 1.4 cm/decade); subscapular—β: 0.9 cm/decade (0.7, 1.4 cm/decade)], but not in women.

Secular trends in the prevalence of high, age-standardized levels are shown in Figure 2. Among men, the prevalence of high levels of BMI (obesity), waist circumference, and triceps skinfold increased by >50% over the 20 y, but the increase in a high subscapular skinfold was smaller. Among women, the prevalence of a high subscapular skinfold in 2007–2010 was fairly similar to the prevalence in 1988–1994, but the prevalence of a high triceps skinfold was ~3 percentage points lower than the prevalence in 1988–1994.

We then examined whether the secular trends in the skinfold thicknesses in women varied by race, age, or BMI status. Although there were differences in the trends by age and race, with the decrease in triceps skinfold thickness from 2003–2004 through 2009–2010 being most evident in 40- to 59-y-olds and in white women, the interaction was most pronounced for BMI status ($P < 0.0001$ for the BMI × year interaction term in a regression model controlling for race and age). Among normal-weight women (Figure 3, left panel), there was relatively little change in any of the body size measures over time, although waist circumference increased by ~3% over the 20-y period. However, mean levels of the 2 skinfolds in both overweight (Figure 3, middle panel) and obese (Figure 3, right panel) women decreased over time. Among obese women, mean levels of both the triceps and subscapular skinfolds were 7–10% lower in 2007–2010 than in 1988–1994 ($P < 0.0001$ for each trend). These trends differed substantially from the increases seen in BMI (3% increase) and waist circumference (4% increase) over the 20-y period in obese women.

We then examined the possible effects of the missing triceps skinfold data in women. Trends in mean levels of BMI, triceps skinfold, and waist circumference over the 20-y period are shown in Figure 4 with the use of 3 methods for the missing values: *1*) excluding the missing triceps skinfold values (circles), *2*) recoding values that exceed the capacity of the caliper to 50 mm (slightly greater than the maximum in 1988–1994) (triangles), and *3*) multiple imputation (squares). For BMI (Figure 4, left panel) and waist circumference (Figure 4, right panel), restricting the analyses to subjects who had a measured triceps skinfold slightly reduced the magnitude of the secular trends, but mean levels increased by ~1.5 (BMI) and 5 cm (waist) over the period. Including the persons for whom the triceps skinfold exceeded the capacity of the caliper resulted in BMI and waist circumference values showing trends that were similar to those based on all subjects.

For the triceps skinfold (Figure 4, middle panel), patterns over the 20-y period were similar for the 3 techniques, with each showing a marked spike in 2003–2004. However, levels were lowest if the women whose measurements exceeded the caliper capacity were excluded, and were highest if these values were recoded. All 3 methods indicated that the mean triceps skinfold thickness of women in 2009–2010 was similar to that in 1988–1994, despite the substantial increases in levels of BMI and waist circumference over this period.

DISCUSSION

Our findings demonstrate that various indicators of body fatness are not interchangeable when examining secular trends over time. Whereas secular trends in the 4 indicators were fairly similar in men over the ~20-y period, in women, the trends in skinfolds differed markedly from those for BMI (+2.1) and waist circumference (+6 cm). The mean triceps skinfold of women was no different in 2009–2010 than it was in 1988–1994, whereas the mean subscapular skinfold increased by only 0.5 mm over this period. Although there are other possibilities that could explain these contrasting patterns, it is likely that our findings are due to the difficulties in standardizing skinfold thickness measurements across observers over an extended time period.

Few long-term studies of skinfolds have obtained measurements on >2 occasions, but other investigators have found contrasting patterns in trends for BMI and skinfolds. Data from 7 examinations of 5- to 14-y-olds in the Bogalusa Heart Study (33), for example, showed that the prevalence of high BMIs and triceps skinfolds increased by ~2-fold from the 1970s through the 1990s. However, the increases in high levels of BMI were fairly monotonic, whereas the prevalence of a high skinfold increased initially from 15% (1973) to 37% (1981), but then decreased to 25–27% (1983–1987). Similar to our findings in the NHANES, a substantial decrease in the prevalence of high levels of triceps skinfolds between 2003–2004 and 2005–2006 in women was previously observed (7), but possible reasons for this decrease were not discussed. Longitudinal studies have also shown that skinfold changes do not necessarily parallel those for DXA-calculated total fat (34).

It is known that the reproducibility of skinfold measurements can be low (13) because of differences in examiner technique, dynamic compression, and subject hydration. Furthermore, the SD of interobserver differences in skinfold measurements can be large relative to the mean thickness (13, 35, 36), and estimates of the mean triceps skinfold of young women can vary by 2-fold (12.8–25.4 mm) (37) across studies even after controlling for body composition. These interobserver differences also could influence secular trends over periods of several decades, and it is possible that these errors may be largest in very lean (38) and obese persons (36, 39–41), groups in which skinfolds are difficult to measure. The ratio of interobserver unreliability (comprising measurement errors and intrasubject variations) to intraobserver unreliability is also ~2-fold greater in women than in men (36). These differences may, in part, explain the difference across sex and BMI categories observed in the current study. Although the NHANES has collected information on skinfold measurements made by multiple observers since 1999–2000, these data are not publicly available.

Additional analyses indicated that whereas the correlation between BMI and waist circumference in women did not change across the 7 surveys (r = ~0.90), the relation of BMI levels to both skinfolds decreased from ~0.78 (1988–1994) to between 0.67 and 0.73 (1999–2010). The predicted (based on regression models that controlled for sex, age, and race) relation of BMI to levels of the skinfolds and waist circumference in 3 surveys for 50-y-old white adults is shown in **Supplemental** Figure 2. Estimated levels of the triceps and subscapular skinfolds at a given BMI decreased over time in women (bottom panels). At a

BMI of 30, for example, the predicted triceps skinfold in 50-y-old white women was 30 mm in 1988–1994, but 28 mm in 2009–2010.

Previous studies of secular trends in skinfold thicknesses in surveys conducted by the National Center for Health Statistics have indicated that the prevalence of high levels increased over various time periods (7, 9), but it is not clear how several methodologic issues were handled. For example, examinations conducted in 1988–1994 and subsequent studies have used Holtain calipers, but earlier studies used Lange calipers (7, 42). Inter-caliper differences in skinfold values have been well documented (14–16, 43), with values from Holtain calipers being ~2–5 mm (mean) lower (16, 17). All 7 examinations in the current analysis used Holtain calipers and followed similar protocols (44, 45), but there were some differences. For example, the capacity of the Holtain caliper in the NHANES III was 50 mm (21), whereas the maximum capacity in subsequent years was 45 mm (7). In one analysis, we recoded triceps skinfolds that were noted to exceed the capacity of the caliper to 50 mm, and this also indicated that there was no secular increase in women.

Adults who were missing information on skinfolds tended to have high BMIs (Table 1). Because an analysis restricted to persons with nonmissing skinfolds would be biased, we used multiple imputation to estimate the values of the missing skin-folds from several characteristics, including BMI, circumferences, and DXA-estimated body fatness. Among persons with measured skinfolds, the multiple R^2 of a regression model predicting triceps skinfold thickness from these characteristics was 0.74, suggesting that the imputed values are likely to be fairly accurate. We also performed sensitivity analyses that confirmed that the secular trends in skinfolds in women differed substantially from those for BMI and waist circumference.

Although we feel that our results emphasize the difficulties in interpreting skinfold thickness measurements over time and across examiners, it is possible that the differing patterns in the body size measures in women reflect actual changes in body composition or in the distribution of body fatness. If, for example, the muscle mass of women increased, this could account for an increase in BMI without corresponding increases in skinfolds. We think, however, that this is very unlikely. We observed large increases in the waist circumference of women, and in men, the 4 indicators showed fairly similar trends. We know of no explanation for why the muscle mass of women, but not men, would have increased over time, and others have concluded that secular increases in BMI largely reflect increases in body fatness (46, 47). We feel that our findings concerning skinfolds in women most likely are due to the difficulty involved in standardizing these measurements over time and across observers, along with the fairly large number of measurements that exceeded the caliper capacity.

In summary, we found that secular trends in skinfolds from 1988–1994 through 2009–2010 in women (but not men) differed substantially from trends in BMI and waist circumference. These contrasting patterns were particularly evident in obese women, a group in which the measurement of skinfolds is known to be technically difficult. Although it has been suggested that skinfold thicknesses could be used to monitor secular trends in obesity (7), our results emphasize that this is not feasible. Our results are also likely to be relevant to the estimation of body fatness from equations developed in other studies that use skinfold thickness measurements. Although >600 equations have been developed for this purpose (37, 40, 48), it may not be possible to apply equations developed by one set of observers to skinfolds measured in other studies.

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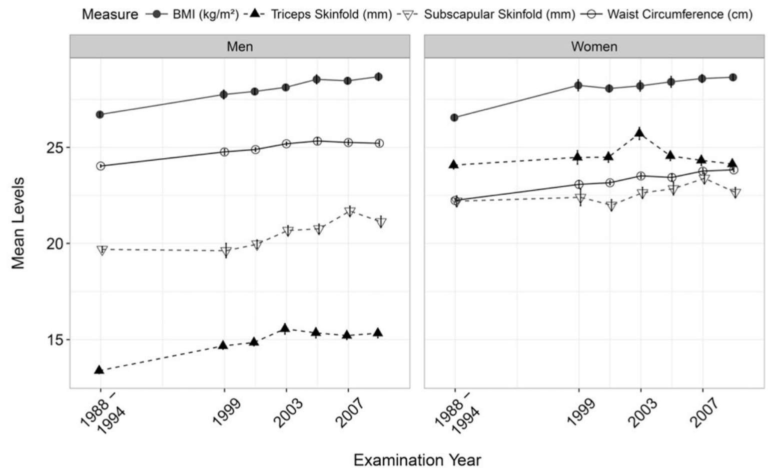

FIGURE 1.

Mean ± SE age-standardized levels of body size measures from 1988–1994 through 2009–2010 in US adults. Values of waist circumference were divided by 4 so they could be displayed on the same scale. The *n* values for each sex-year estimate are shown in Table 2, and range from 2043 (men in 1999–2000) to 8748 (women in 1988–1994).

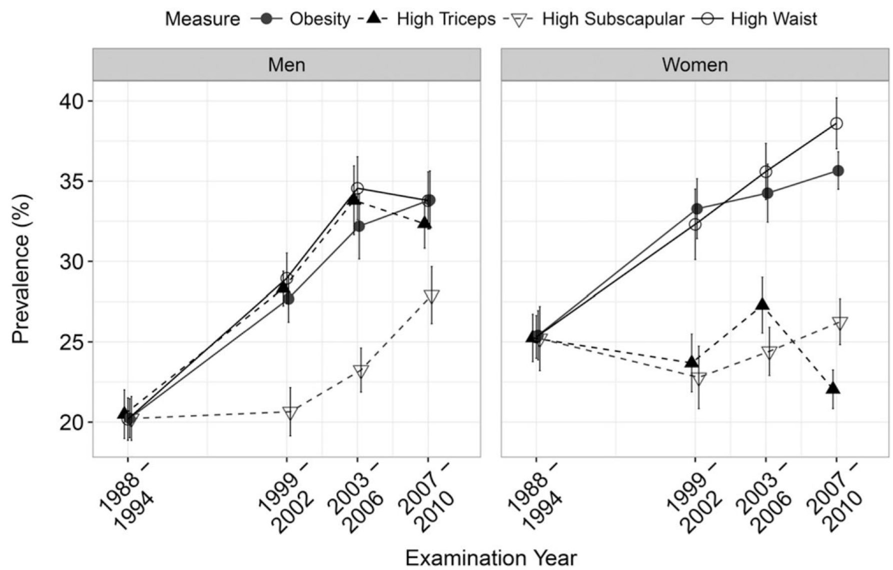

FIGURE 2.

Prevalence (95% CI) of high age-standardized levels of body size measures from 1988–1994 through 2009–2010 in US adults. The 2-y estimates were combined into 4-y groups. The *n* values in 1988–1994 are 7931 (men) and 8748 (women); *n* values for other estimates range from 4268 to 5841.

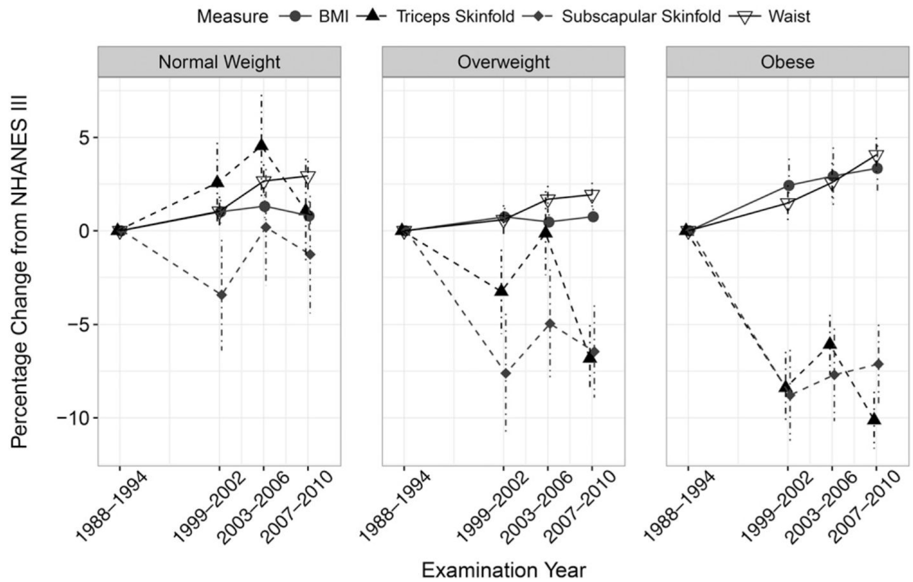

FIGURE 3.
Interaction between secular trends and body size measures with BMI status in US women from 1988–1994 through 2009–2010. The 2-y cycles were combined into 4-y groups. The y-axis shows race- and age-adjusted differences (and 95% CIs) in mean levels, expressed as a percentage, between the 1988–1994 timeframe and subsequent examinations. *n* Values in 1988–1994 range from 2592 to 3518; *n* values for other estimates range from 1305 (overweight women in 1999–2002) to 2339 (obese women in 2007–2010).

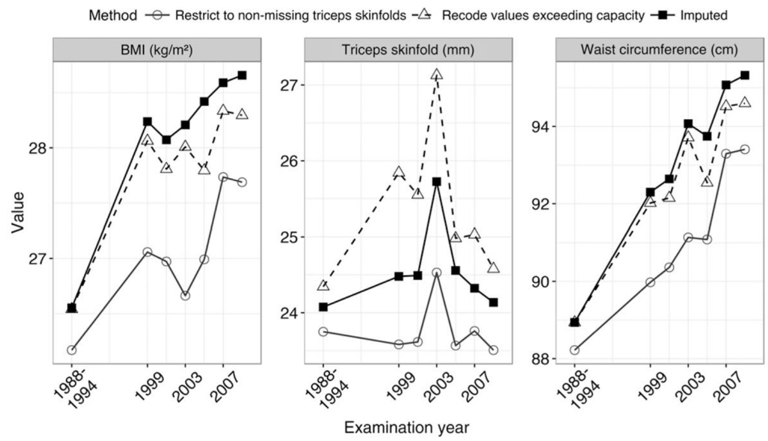

FIGURE 4.

Secular trends in US women from 1988–1994 through 2009–2010 according to whether missing values are *1*) excluded if the triceps skinfold thickness is missing, *2*) recoded to 50 mm if the skinfold exceeded the caliper capacity, or *3*) imputed. *n* Values for the complete (imputed) estimates are 8748 in 1988–1994, and range from 2074 to 3037 for the other years. Compared with these *n* values, the sample sizes for the estimates based on recoding are ~6% lower, and those based on excluding the missing values are ~11% lower.

TABLE 1

BMI levels according to missingness of the triceps skinfold, by sex and examination year in adults; NHANES 1988–1994 through 2009–2010

Triceps skinfold category	Men				Women			
	n (%)[1]	BMI percentiles[2]			*n* (%)[1]	BMI percentiles[2]		
		10	50	90		10	50	90
1988–1994								
Measured	7530 (94.9)	21.4	25.9	32.1	8039 (91.9)	19.9	25.0	34.1
Could not obtain	371 (4.7)	21.8	27.5	37.7	460 (5.3)	19.3	25.2	36.5
Exceeded caliper capacity	32 (0.4)	40.4	46.6	59.6	249 (2.8)	34.4	41.4	51.3
1999–2002								
Measured	4078 (95.7)	21.7	26.9	33.7	3787 (88.7)	20.4	26.1	35.0
Could not obtain	125 (2.9)	25.6	32.5	42.3	137 (3.2)	22.5	34.2	48.2
Exceeded caliper capacity	59 (1.4)	33.0	42.5	53.1	344 (8.1)	30.0	38.2	47.8
2003–2006								
Measured	4140 (92.5)	22.0	27.4	34.2	3548 (82.3)	20.3	25.8	34.6
Could not obtain	306 (6.8)	24.7	33.0	42.4	436 (10.1)	23.3	31.9	42.9
Exceeded caliper capacity	28 (0.6)	39.0	42.5	53.6	329 (7.6)	32.0	39.6	50.4
2007–2010								
Measured	5285 (93.8)	22.0	27.6	34.8	5194 (88.9)	20.5	26.6	36.5
Could not obtain	302 (5.4)	23.9	31.3	43.0	383 (6.6)	21.9	32.4	45.3
Exceeded caliper capacity	48 (0.9)	37.0	43.8	63.4	264 (4.5)	32.2	39.7	52.3

[1] *n* and unweighted proportion in each period and triceps skinfold category.

[2] BMIs are in kg/m^2 and are weighted estimates that have been age-standardized. Values are the percentile of BMI levels for the specified sex-year-triceps category. The “could not obtain” and “exceeded capacity” categories are mutually exclusive.

TABLE 2

Age-standardized levels of body size measures according to sex and examination period in adults; NHANES 1988–1994 through 2009–2010[1]

Year	*n*	BMI, kg/m^2	Triceps skinfold, mm	Subscapular skinfold, mm	Waist circumference, cm
Men					
1988–1994	7933	26.7 ± 0.1	13.4 ± 0.2	19.7 ± 0.2	96.1 ± 0.2
1999–2000	2043	27.8 ± 0.2	14.7 ± 0.2	19.6 ± 0.4	99.1 ± 0.6
2001–2002	2219	27.9 ± 0.1	14.9 ± 0.2	20.0 ± 0.2	99.6 ± 0.4
2003–2004	2237	28.1 ± 0.1	15.6 ± 0.3	20.7 ± 0.2	100.8 ± 0.3
2005–2006	2237	28.5 ± 0.2	15.4 ± 0.3	20.8 ± 0.2	101.3 ± 0.6
2007–2008	2746	28.5 ± 0.2	15.2 ± 0.2	21.7 ± 0.3	101.0 ± 0.5
2009–2010	2889	28.7 ± 0.2	15.3 ± 0.2	21.1 ± 0.3	100.9 ± 0.5
Change per decade		+1.1 (0.9, 1.3)*	+1.1 (0.9, 1.4)*	+1.1 (0.7, 1.4)*	+3.0 (2.5, 3.4)*
Women					
1988–1994	8748	26.6 ± 0.1	24.1 ± 0.2	22.2 ± 0.3	88.9 ± 0.3
1999–2000	2074	28.2 ± 0.3	24.5 ± 0.4	22.4 ± 0.4	92.3 ± 0.8
2001–2002	2194	28.1 ± 0.2	24.5 ± 0.3	22.0 ± 0.3	92.6 ± 0.4
2003–2004	2194	28.2 ± 0.3	25.7 ± 0.3	22.6 ± 0.3	94.1 ± 0.5
2005–2006	2119	28.4 ± 0.3	24.6 ± 0.2	22.8 ± 0.3	93.7 ± 0.7
2007–2008	2804	28.6 ± 0.2	24.3 ± 0.3	23.4 ± 0.3	95.1 ± 0.5
2009–2010	3037	28.7 ± 0.1	24.1 ± 0.2	22.7 ± 0.3	95.3 ± 0.4
Change per decade		+1.1 (0.9, 1.3)*	+0.1 (–0.2, 0.4)	+0.4 (0, 0.7)	+3.5 (2.9, 4.0)*

[1] Values are means ± SEs. *P* values for linear trend in year of examination were assessed in a regression model that controlled for age and race and accounted for the uncertainty of the imputed values across the 5 sets of values.

* $P < 0.001$.