

Anthropometric assessment of 10-y changes in body composition in the elderly¹⁻⁴

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ABSTRACT

Background: An increased central distribution of fat with advancing age is associated with chronic metabolic and cardiovascular abnormalities. Little is known about the magnitude or pattern of fat distribution and its association with healthy aging.

Objective: This study describes ≈ 10 -y changes in body composition at 11 anthropometric sites in elderly persons and the metabolic and physical activity factors associated with these changes.

Design: Skinfold thicknesses, girths, body fat by hydrodensitometry, physical activity by questionnaire, and metabolic variables were examined twice, 9.4 ± 1.4 y apart, in 54 men and 75 women aged 60.4 ± 7.8 y at baseline.

Results: Subcutaneous fat declined (-17.2% ; $P < 0.001$), whereas total fat mass increased (7.2% ; $P < 0.05$). Waist and hip circumference changes were the best anthropometric predictors of total fat mass change ($r^2 = 0.40-0.65$, $P < 0.0001$). Thigh girth change was more strongly associated with fat-free mass change ($r^2 = 0.22$, $P < 0.01$) than with fat mass change ($r^2 = 0.07$, $P < 0.05$) in women. An increase in physical activity was associated with an attenuation of thigh girth decline in men and women (F ratio = 5.13, $P < 0.007$). Traditional metabolic markers of visceral adiposity (triacylglycerol, glucose, and total cholesterol) were not significantly related to the change in waist circumference.

Conclusions: Skinfold thicknesses cannot be used to assess changes in body fat mass because of age-related fat redistribution. Higher levels of physical activity can attenuate the decline in appendicular lean tissue expected over 10 y. Waist and thigh girths, rather than skinfold thicknesses, should be considered for use in longitudinal studies in the elderly because the changes in these girths capture increased abdominal adiposity and sarcopenia, respectively. *Am J Clin Nutr* 2004;80:475-82.

KEY WORDS Aging, body composition, visceral fat, subcutaneous fat, follow-up study, physical activity

INTRODUCTION

The increase in whole-body adipose tissue throughout adulthood is well documented by many techniques. Development of chronic diseases associated with aging can be attributed in part to this increased adiposity. However, it is the regional measures of fat deposition that have been more specifically linked to the chronic metabolic and cardiovascular abnormalities, including insulin resistance, hyperlipidemia, hypertension, and coronary artery disease, that develop with advancing age (1, 2). Although

anthropometry may be less precise than more sophisticated techniques used to assess regional body composition (ie, computed tomography, magnetic resonance imaging, and dual-energy X-ray absorptiometry), its simplicity allows it to be used in large population-based studies to assess body-composition changes over time, as well as in clinical and field situations where access to technology is limited. Additionally, if used in combination with measures of whole-body fat, anthropometry can identify distinct fat redistribution changes that occur in the elderly.

In cross sectional studies, increases in subcutaneous fat have been observed with advancing age up to ≈ 60 y (3-5). Age-related differences in regional body composition are also documented by higher waist diameters (3, 5), higher waist-to-hip or waist-to-thigh ratios (6), and lower girths in the limbs in older than in younger subjects (5, 7-11). To our knowledge, no longitudinal study has addressed the redistribution of fat stores as measured by skinfold-thickness and girth measures of both the trunk and the limbs in the same older population or in conjunction with whole-body measures of fat tissue.

The purpose of the present study was to describe the magnitude of the change in appendicular and trunk skinfold thicknesses and circumferences over ≈ 10 y in relation to the change in total body fat, metabolic parameters, and physical activity in men and women initially aged ≈ 60 y. The primary outcomes were fat distribution and fat estimates from anthropometric measures.

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We hypothesized that, because of the age-associated increase in intraabdominal adipose tissue, waist circumference would be the best predictor of the change in whole-body fat mass over the follow-up period.

SUBJECTS AND METHODS

The subjects ($n = 141$) were initially tested between 1984 and 1991. Follow-up testing occurred 5–12 y later. Study design, recruitment, and loss to follow-up information were described previously (12). Subjects taking medications that could influence body composition ($n = 6$) or who had a knee or hip arthroplasty ($n = 6$), both of which could preclude a meaningful interpretation of body weight change or invalidate the fat-free mass density assumption in the underwater weighing algorithms, were excluded from the present analysis. Therefore, 129 subjects are included in this analysis. The study purpose and procedures, which were approved by the Institutional Review Board of the Tufts–New England Medical Center, were discussed with the volunteers, who subsequently gave written informed consent.

Total body fat by hydrodensitometry

The subjects were tested in the morning after they had fasted overnight. Their weight underwater to the nearest 0.01 kg was measured by using a Sauter Scale (model K120; Mettler Instruments, Highstown, NJ) while they were coached to expire maximally as previously described (13). Each subject performed 5–10 consecutive trials. Densities of fat and fat-free tissues of 0.9 and 1.1 g/cc, respectively, were used to calculate fat mass and fat-free mass from total body density obtained from the underwater weight measurements after correction for estimated residual volume (14). Four subjects, measured twice within 14 d, showed a CV for fat mass of 1.4%. Six subjects refused or were unable to perform the underwater weighing procedure at follow-up. Their baseline and follow-up skinfold-thickness data are included in this analysis.

Anthropometric assessment

All anthropometric measurements were performed by the same investigator at both the baseline and the follow-up assessments. Skinfold thicknesses were measured on the right side with the subjects in a relaxed standing position with their weight distributed evenly on both legs. An average of 3 values was used. The following skinfold-thickness measures were made with a Lange skinfold caliper (Cambridge Scientific Industries, Cambridge, MD) to the nearest 0.5 mm: 1) vertical triceps skinfold thickness halfway between the acromion and olecranon processes, 2) vertical biceps skinfold thickness at the same level as the triceps skinfold thickness above the antecubital fossa, 3) subscapular skinfold thickness just below the inferior tip of the scapula, 4) suprailiac skinfold thickness as an oblique fold on the iliac crest in the midaxillary line, 5) midaxillary skinfold thickness in the midaxillary line at the level of the zygoid process in a vertical plane, and 6) vertical abdominal skinfold thickness adjacent to the umbilicus. Abdominal skinfold thickness exceeded the upper limit of the skinfold caliper (67 mm) in one subject at baseline and in 3 subjects at follow-up. The following circumferences were measured with a Gulick II tape (Country Technologies, Gays Mills, WI) to the nearest 0.1 cm and on the right side where relevant: 1) midarm at the level of the triceps skinfold; 2) abdominal at the site of the natural waist, taken as the

smallest circumference between the bottom of the rib cage and the iliac crest; 3) hip at the largest circumference of the buttocks; 4) midhigh at the level halfway between the top of the patella and the inguinal crease, and 5) calf at the largest circumference between the knee and the ankle malleoli.

Computerized tomography

Results from computerized tomography (CT) scans of the midhigh at baseline and follow-up for a subset of subjects are included to document the regional changes in fat and fat-free tissues relative to change in thigh girth. Eight men in the cohort had a CT scan of the left leg during the baseline evaluation as part of their participation in another study. A CT scan of the thigh was performed halfway between the pubic symphysis and the lower pole of the patella. At this time, a muscle biopsy was also performed at this site. The scanner was a third generation Siemens DR3 (Erlanger, Germany) operating at 125 kV peak and 520 mA and with a slice width of 8 mm and a scanning time of 7 s. At the follow-up exam, the scan of the same thigh was obtained at the level of the biopsy scar by using a General Electric Highspeed Advantage CT scanner (Milwaukee) operating at 100 kV peak and 170 mA and with a slice width of 10 mm and a scanning time of 1 s.

Total thigh area, muscle area, and bone areas were measured by manual planimetry (model 317E; Gebruder Haff GMBH, Germany) on the CT film images by one investigator. Inter- and intramuscular fat was not quantified separately and is therefore included in the muscle cross-sectional area measurements. Subcutaneous fat was determined by subtracting the muscle and bone areas from the total thigh area. The error of the planimetry method was <1.5% CV for the estimation of muscle area 3 times by a single investigator.

Physical activity

Physical activity habits were measured to assess the influence of this behavior on body-composition changes. Energy expenditure from sports and recreational activities during the previous year was estimated by using a questionnaire developed for the Harvard Alumni Health Study (15). Subjects were queried in an open-ended manner at baseline and follow-up by the same investigator. Total energy per year for each activity was calculated by using total minutes, body weight, and metabolic equivalent (MET) values from standard tables (16). Energy expenditures from all activities for the year were summed and divided by 52 to give an average weekly estimate. The error for repeated assessments 2 wk apart was 2.0% CV.

Blood analyses

Glucose, triacylglycerol, and total cholesterol were measured to assess metabolic markers generally associated with visceral adiposity. Blood samples were obtained after a 12–14-h overnight fast. Cholesterol, triacylglycerol, and glucose analyses on a subset of subjects ($n = 38$) were not included in this analysis because they were performed using different analytic techniques at baseline. Five subjects did not have complete data. For all other subjects ($n = 86$), the analytes were measured on similar clinical chemistry analyzers by the same manufacturer at both time points (Cobas Mira Analyzer, Roche Diagnostic Systems Inc, Indianapolis). Reagents changed over the study period; however, the basic methods did not. Glucose, cholesterol, and triacylglycerol

TABLE 1
Subject characteristics at baseline and change over the follow-up period¹

	Women (n = 75)		Men (n = 54)	
	Baseline	Change	Baseline	Change
Age (y)	60.1 ± 7.8	9.3 ± 1.3 ²	60.6 ± 7.8	9.4 ± 1.5 ³
Weight (kg)	65.0 ± 11.1	1.1 ± 5.2 ²	77.2 ± 8.1	0.0 ± 3.7
Height (cm)	162.2 ± 5.6	-0.8 ± 1.2 ³	175.5 ± 5.9	-0.7 ± 1.2 ³
BMI (kg/m ²)	24.7 ± 3.7	0.7 ± 2.0 ²	25.1 ± 2.6	0.2 ± 1.2
Fat mass (kg)	22.4 ± 8.4	1.3 ± 4.4 ²	18.5 ± 6.0	1.0 ± 3.2 ²
Body fat (%) ⁴	33.5 ± 7.6	1.3 ± 4.9 ²	23.8 ± 6.4	1.2 ± 3.3 ²
Physical activity (kcal/wk)	979 (166–1562)	65 ± 1170	1820 (273–2539)	-543 ± 1847 ²
Plasma glucose (mg/dL) ⁵	80.7 ± 9.6	10.6 ± 12.3 ³	85.8 ± 13.1	11.9 ± 16.0 ³
Triacylglycerol (mg/dL) ⁵	95.1 ± 50.5	36.7 ± 50.8 ³	112.4 ± 55.1	32.6 ± 63.9 ³
Total cholesterol (mg/dL) ⁵	216.3 ± 40.5	2.6 ± 41.3	212.4 ± 42.5	-6.7 ± 37.4

¹ All values are $\bar{x} \pm SD$, except for physical activity at baseline, for which the values are medians and interquartile ranges.

^{2,3} Significant change from baseline: ² $P < 0.05$, ³ $P < 0.01$.

⁴ $n = 71$ women and 52 men at both baseline and follow-up.

⁵ $n = 49$ women and 36 men.

were measured by coupled enzymatic, endpoint procedures (17–21). The intraassay and interassay CVs for glucose, cholesterol, and triacylglycerol were 2.0% and 2.5%, 2.0% and 2.5%, and 2.7% and 3.0%, respectively.

Statistical analysis

Statistical analyses were performed by using SYSTAT for WINDOWS (version 10; SPSS Inc, Chicago). Variables are reported as means \pm SDs in the text. All variables were found to be normally distributed, except for physical activity. Repeated-measures analysis of variance was used to assess change in body composition and anthropometric variables from baseline to follow-up, with adjustment for years of follow-up. Comparisons of physical activity between the sexes at baseline and over time were made by using the Kruskal-Wallis test. Linear regression analysis was used to assess the association between anthropometric and whole-body measures of fat and lean mass. Correlation coefficients between body composition, physical activity, and metabolic variables were calculated by using Pearson's product-moment correlation. The square root of the physical activity data was used in the correlation analysis. Analysis of covariance with adjustment for appropriate covariates (*see text*) was used to assess differences between groups distinguished by physical activity changes. A Tukey's post hoc test was used if a significant F ratio was found. P values were considered statistically significant at $P < 0.05$.

RESULTS

Subject characteristics are presented in **Table 1**. The subjects were 60.4 ± 7.8 y of age (range: 46–78 y) at the baseline assessment and were studied on average 9.4 ± 1.4 y later. Body weight increased significantly ($P < 0.05$) in the women over the follow-up period and was accounted for entirely by an increase in fat mass ($P < 0.05$; **Table 1**). The changes in body weight and fat mass in the women ranged from -8.8 to 19.4 kg and from -7.0 to 15.8 kg, respectively. Body weight in the men did not change significantly, whereas absolute fat mass increased significantly and to a similar extent as in the women ($P < 0.05$). The changes in body weight and fat mass in the men ranged from -9.9 to 8.6 kg and from -5.6 to 10.8 kg, respectively.

Energy expenditure in recreational and sports activities in the women was lower than in the men at baseline ($P < 0.05$) and remained unchanged over the follow-up period. In contrast, the men showed a decline in energy expenditure in these activities over the follow-up period ($P < 0.05$). Plasma glucose and triacylglycerol increased ($P < 0.01$), whereas cholesterol remained unchanged, in both the men and the women.

Changes in skinfold thickness and girth

Skinfold-thickness measurements are shown in **Table 2**. All skinfold-thickness measures, except for those at the subscapular site, declined significantly over the follow-up period in both the women and the men ($P < 0.05$ to $P < 0.001$). The sum of all 6 skinfold-thickness sites also declined, by 33.9 mm in the women (range: -171.7 to 64.5 mm) and by 35.2 mm in the men (range: -121.4 to 48.1 mm) ($P < 0.001$). The relative decline in skinfold thickness was not significantly different between the men and the women at all sites, except for the midaxillary site, for which the decline was greater in the men (**Figure 1**).

Circumference measurement results are shown in **Table 3**. Arm and thigh circumference declined in both the men and the women ($P < 0.001$). The women (-8.2%) showed a proportionally greater decline in thigh circumference than did the men (-5.6%; $P < 0.02$), whereas the men had a greater decline in arm circumference (men: -5.2%; women: -1.6%; $P < 0.002$; **Figure 1**). Waist circumference increased significantly in the women ($P < 0.001$) but not in the men, whereas hip circumference decreased significantly in the men ($P < 0.05$). There was no significant change in calf circumference in the men, but there was an increase at that site in the women ($P < 0.002$). Waist-to-thigh and waist-to-arm ratios increased in both sexes over time ($P < 0.001$); however, the waist-to-hip ratio increased significantly only in the women ($P < 0.001$).

Association of anthropometry with whole-body changes in fat mass

Each skinfold thickness and girth was significantly associated with total-body fat mass and percentage body fat at both the baseline and the follow-up assessments in both the men and the

TABLE 2
Skinfold thicknesses at baseline and change over the follow-up period

Site	Women			Men		
	<i>n</i>	Baseline	Change	<i>n</i>	Baseline	Change
		<i>mm</i>	<i>mm</i>		<i>mm</i>	<i>mm</i>
Biceps	74	19.4 ± 8.3 ¹	-6.7 ± 6.4 ²	54	10.6 ± 5.2	-2.7 ± 4.8 ²
Triceps	75	27.3 ± 7.8	-5.7 ± 6.7 ²	54	17.8 ± 7.2	-5.4 ± 1.1 ²
Subscapular	75	25.4 ± 10.5	-3.2 ± 6.8	54	21.7 ± 7.9	0.5 ± 4.5
Suprailiac	71	24.9 ± 11.5	-4.7 ± 11.3 ²	53	20.7 ± 10.4	-2.7 ± 8.5 ³
Abdomen	68	36.6 ± 16.2	-7.3 ± 12.3 ²	42	34.6 ± 14.5	-7.9 ± 12.6 ²
Midaxillary	67	27.7 ± 12.7	-6.1 ± 10.0 ²	42	26.6 ± 10.8	-9.7 ± 7.1 ²
Sum of all sites	65	160.4 ± 59.0	-33.9 ± 39.2 ²	38	135.3 ± 50.6	-35.2 ± 37.3 ²
Sum of trunk sites	66	114.0 ± 44.9	-22.0 ± 29.0 ²	38	106.9 ± 39.9	-26.3 ± 27.7 ²
Sum of limb sites	74	46.7 ± 15.1	-12.3 ± 11.5 ²	54	28.3 ± 11.4	-21.1 ± 8.5 ²

¹ $\bar{x} \pm SD$ (all such values).

^{2,3} Significant change from baseline: ² $P < 0.001$, ³ $P < 0.05$.

women (data not shown). The ability of individual skinfold sites to predict changes in fat mass is outlined in **Table 4**. The change in skinfold thickness was significantly associated with the change in fat mass at each site in the women. The change in total body fat in the women was explained best by the change in skinfold thickness at the triceps (32%) and subscapular (31%) sites. In the men, only the change in skinfold-thickness measures on the trunk (suprailiac and subscapular site) was significantly

associated with the change in total body fat. The subscapular site showed the strongest association with change in total body fat in the men, but explained only 22% of the variance.

The change in each circumference measure was significantly related to the change in total-body fat mass in both the men and the women (Table 4). Considering all anthropometric measures, the changes in waist and hip circumferences were the best predictors of the change in fat mass for women and explained 53% and 63%, respectively, of the variance in the fat mass change. Change in waist or hip circumference explained 42% and 40%, respectively, of the change in fat mass in the men. Although the change in waist-to-hip ratio was significantly associated with the change in fat mass, it explained little (15%) of the variance.

A decrease in the sum of 6 skinfold thicknesses was accompanied by either decreases or increases in total body fat (**Figure 2**). An apparent redistribution of fat was observed in 39% of the subjects as measured by a decline in subcutaneous fat stores while total fat increased. An increase in skinfold thickness was always accompanied by an increase in fat mass.

Associations of whole-body measures of fat and fat-free mass with regional anthropometric changes

To determine whether girth changes reflected whole-body fat or fat-free mass change, these measures were simultaneously used to predict girth changes. The changes in arm, thigh, calf, and waist girths were independently and significantly predicted by both the change in whole-body fat mass and the change in whole-body fat-free mass (**Table 5**). The change in whole-body fat but not in fat-free tissue was associated with the change in hip girth. In the women, the change in fat-free mass explained almost 3 times as much of the variance (22%) in thigh circumference change as did the change in fat mass (7%). Additionally, the coefficient for change for fat-free mass was 4 times that for fat mass. In the men, the coefficients for fat and fat-free tissue change were similar when regressed on thigh girth change. However, with the use of the regional assessment of fat and lean tissue areas by CT in a subset of men, the decrease in thigh area ($-9.0 \pm 10.6\%$) was accounted for entirely by the decrease in muscle area ($-11.4 \pm 12.2\%$), whereas subcutaneous fat area remained unchanged ($1.3 \pm 11.7\%$).

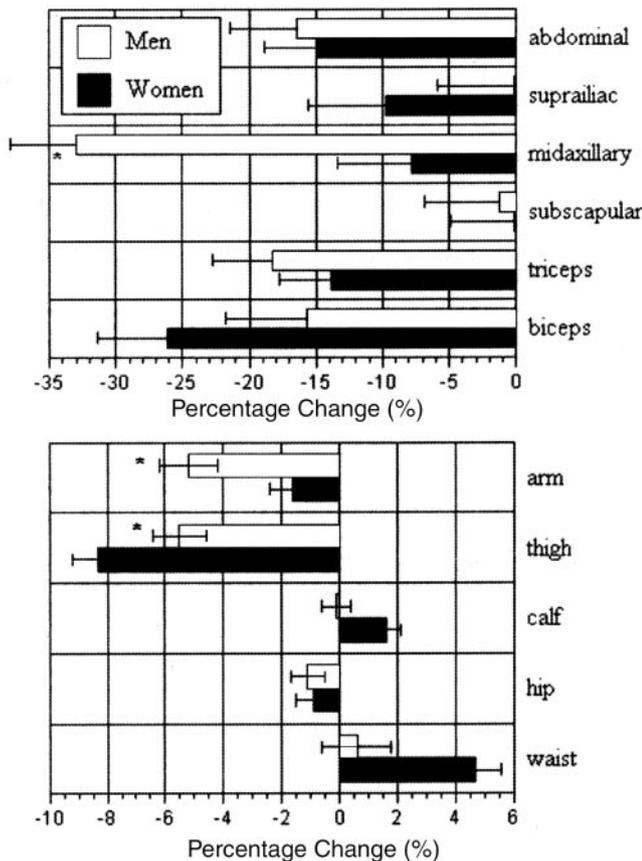


FIGURE 1. Mean ($\pm SE$) percentage change in skinfold-thickness and girth measures at appendicular and trunk sites. *Significantly different from women, $P < 0.05$.

TABLE 3
Circumferences at baseline and change over the follow-up period

Site	Women			Men		
	<i>n</i>	Baseline	Change	<i>n</i>	Baseline	Change
Midarm	74	29.1 ± 3.5 ¹	-0.5 ± 2.3 ²	54	31.7 ± 2.8	-1.9 ± 2.1 ²
Calf	67	35.2 ± 3.0	0.4 ± 1.4 ³	50	37.1 ± 2.5	-0.1 ± 1.2
Midthigh	65	54.8 ± 6.0	-4.5 ± 4.4 ²	47	52.7 ± 4.2	-2.4 ± 2.9 ²
Waist	70	78.4 ± 9.4	+4.0 ± 6.8 ²	46	91.4 ± 9.3	+0.8 ± 4.4
Hip	45	102.2 ± 8.2	-1.7 ± 4.3	35	100.5 ± 5.4	-2.7 ± 3.0 ³
Waist-hip ratio	42	0.79 ± 0.05	0.03 ± 0.05 ²	34	0.93 ± 0.05	0.02 ± 0.08
Waist-thigh ratio	64	1.44 ± 0.13	0.22 ± 0.16 ²	41	1.73 ± 0.15	0.11 ± 0.08 ²
Waist-arm ratio	70	2.70 ± 0.18	0.11 ± 0.09 ²	46	2.89 ± 0.22	0.18 ± 0.17 ²

¹ $\bar{x} \pm SD$ (all such values).

^{2,3} Significant change from baseline: ² $P < 0.001$, ³ $P < 0.05$.

Relation of physical activity and metabolic variables with body composition

Percentage body fat was inversely related to physical activity at follow-up ($r = -0.37, P < 0.007$) in the men only. However, none of the anthropometric measures were related to physical activity at baseline or at follow-up in either the men or the women. Those who increased their physical activity (>500 kcal/wk) over the follow-up period showed a smaller ($P < 0.05$) decline in thigh girth (adjusted for baseline age and body mass index, follow-up period, and weight change) than did those who decreased (>500 kcal/wk) their physical activity over the follow-up period (Figure 3).

Plasma triacylglycerol was associated with waist circumference at baseline ($r = 0.43, P < 0.001$) and at follow-up ($r = 0.33, P < 0.001$), but not with the other girths, skinfold thicknesses, fat

mass, or percentage fat. However, neither the change in waist girth nor the change in any body-composition variable was related to the change in plasma triacylglycerol. Similarly, plasma glucose was associated with waist circumference at baseline ($r = 0.22, P < 0.018$) and at follow-up ($r = 0.27, P < 0.02$), but the change in plasma glucose was not associated with the change any of the body-composition variables. Total cholesterol was not associated with any whole-body or regional body-composition measure of fat mass at either baseline or follow-up. However, the change in cholesterol positively correlated with the change in percentage body fat ($r = 0.23, P < 0.011$), but not with change in any of the anthropometric measures.

DISCUSSION

The present study provides comprehensive 10-y longitudinal data for limb and trunk skinfold and circumference changes in older men and women. Similar to the finding that weight stability may mask sarcopenia (22), the results of the present study show that substantial subcutaneous fat losses (-17.2%) mask the increase in total-body fat mass (7.2%) with advancing age. With this pattern of change, it is not surprising that the predictive ability of skinfold measures to estimate fat mass change was relatively low. Trunk circumference measures gave a better estimate of change in total body fat over the 10-y follow-up period.

TABLE 4
Correlation coefficients (r^2) for change (Δ) in anthropometric measures versus change (Δ) in total-body fat mass or lean mass

	Women	Men
Δ Fat mass and the following skinfold thicknesses:		
Δ Biceps	0.10 ¹	0.02
Δ Triceps	0.32 ²	0.04
Δ Subscapular	0.31 ²	0.22 ³
Δ Suprailiac	0.28 ²	0.14 ¹
Δ Abdomen	0.26 ²	0.08
Δ Midaxillary	0.17 ³	0.09
Δ Sum of all 6	0.40 ³	0.14 ¹
Δ Fat mass and the following circumferences:		
Δ Waist	0.53 ²	0.42 ²
Δ Hip	0.65 ²	0.40 ²
Δ Waist-hip	0.15 ³	0.15 ¹
Δ Midarm	0.37 ²	0.22 ³
Δ Thigh	0.12 ³	0.22 ³
Δ Calf	0.30 ²	0.15 ³
Δ Fat-free mass and the following circumferences:		
Δ Midarm	0.32 ²	0.11 ³
Δ Thigh	0.23 ²	0.06 ¹
Δ Calf	0.25 ²	0.02

¹ $P < 0.05$.

² $P < 0.0001$.

³ $P < 0.001$.

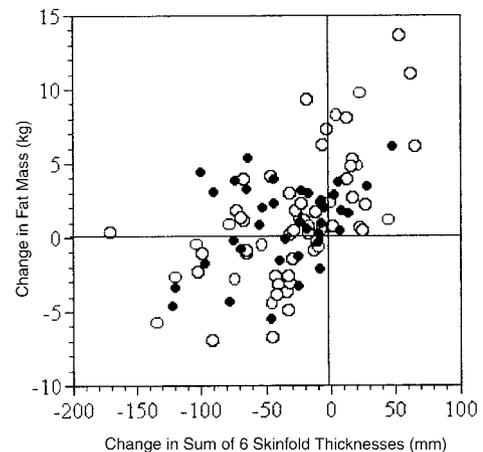


FIGURE 2. Change in whole-body fat mass plotted as a function of the change in the sum of 6 skinfold thicknesses in women (○) and men (●). $r = 0.20, P < 0.001$.

TABLE 5

Regression coefficients (β) and partial correlation coefficients (r^2) for multiple regression analysis of changes in whole-body fat mass and fat-free mass simultaneously regressed on girth measures

Girth change	Women				Men			
	Fat mass change		Fat-free mass change		Fat mass change		Fat-free mass change	
	β	r^2	β	r^2	β	r^2	β	r^2
Arm	0.263 ¹	0.37	0.499 ¹	0.39	0.257 ¹	0.25	0.325 ¹	0.19
Thigh	0.189 ²	0.07	0.774 ¹	0.22	0.418 ¹	0.19	0.400 ²	0.11
Calf	0.147 ¹	0.26	0.203 ¹	0.14	0.203 ¹	0.36	0.142 ²	0.10
Waist	0.738 ¹	0.36	1.579 ¹	0.38	0.906 ¹	0.38	0.810 ¹	0.20
Hip	0.742 ¹	0.64	0.424	0.08	0.625 ¹	0.42	0.263	0.07

¹ $P < 0.01$.

² $P < 0.05$.

Unique to our longitudinal anthropometric analyses are the concurrent data describing the changes in whole-body fat. As we and others have seen, the increases or decreases in body weight are generally paralleled by similar changes in subcutaneous fat (23, 24). By including whole-body measures of fat, we were able to identify a subgroup of individuals (39% of the study group) in whom subcutaneous fat decreased (-23%) while total body fat increased (11%).

Longitudinal studies including anthropometric measures in subjects older than 60 y are rare and report limited data. Decreases in triceps and subscapular skinfold thicknesses have been observed (25–28). Our data document the decrease in skinfold thickness at 5 of 6 sites, even with overall increasing total body fat. With declining girth and skinfold thickness in the limbs and increased waist circumference with decreased abdominal skinfold thickness, the obvious region of additional fat weight is the intraabdominal region. Although the present study did not directly measure this, greater waist girth is most often accounted

for by increased intraabdominal fat stores (7, 29–31). In the absence of liver or renal disease, as was the case with our subjects, no other cause of increased abdominal girth and reduced cutaneous fat other than intraabdominal fat gain is likely. However, an important limitation of our data is that we cannot conclude how much of the intraabdominal fat gain was in fact visceral fat. The results of a recent study by Ross et al (32), however, suggest that intraabdominal fat and visceral fat are highly correlated.

Thus, we infer that the waist circumference change we saw most likely reflects visceral adipose tissue stores. In contrast, thigh girth was found in several other studies to estimate skeletal muscle mass in both young (33) and elderly (34) subjects. To further these observations, we found in women that the change in thigh girth was more strongly related to the change in fat-free tissue than to the change in fat tissue. Additionally, we found by using CT in a small subset of men that the decline in thigh area was due entirely to a loss of muscle tissue, whereas subcutaneous tissue remained essentially unchanged over the follow-up period. Planimetric methods were not accurate enough to determine changes in intermuscular stores over the follow-up period. However, the observed decline in muscle size may have been underestimated because of the known increase in intermuscular fat that occurs with age (35, 36).

Given the increase in trunk fat observed with advancing age, it is not surprising that the best predictors of body fat change were waist and hip girths. Other investigators have used skinfold thicknesses, girths, weight, height, age, and sex to predict body fat in older subjects. When girths, skinfold thickness, body weight, and age were used as independent predictors of body fat, skinfold sites were generally not included in the prediction equation. More importantly, without skinfold-thickness measures in the equation, the percentage of explained variance in the fat measure (fat mass, body density, or percentage body fat) was higher than for equations with skinfold thicknesses alone (37–41). Furthermore, when skinfold thicknesses were used in prediction equations, simultaneously developed equations on the same population were just as robust with the use of body mass index without any anthropometric measures (40, 42). The underestimation of total body fat in the elderly with the use of skinfold-thickness measurements (40, 43, 44) results in part from the redistribution of fat, not only from extremity to trunk, but also from subcutaneous to intramuscular or intraperitoneal sites (7, 29, 30, 45, 46). Our longitudinal data support the use of waist or

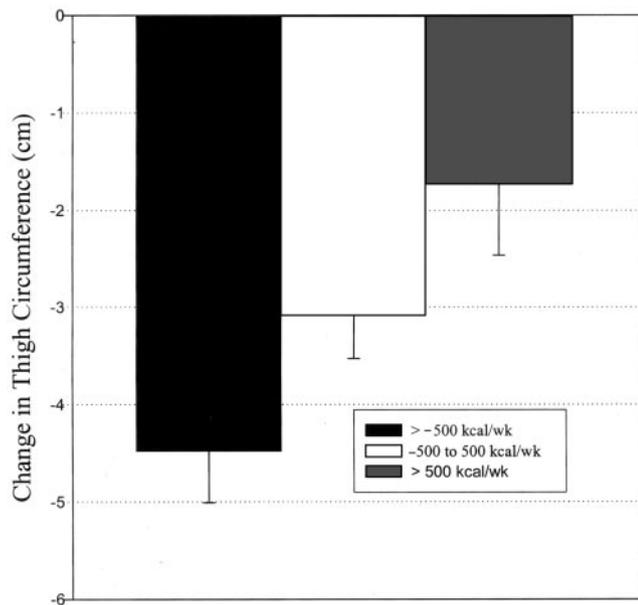


FIGURE 3. Mean (\pm SE) change in thigh circumference by change in physical activity adjusted for baseline age, BMI, follow-up period, and change in weight. Energy expenditure decreased by >500 kcal/wk in 36 subjects, remained between -500 and 500 kcal/wk in 56 subjects, and increased by >500 kcal/wk in 22 subjects.

hip girth as the most robust measure of fat mass changes in the elderly. This finding is especially valuable considering that in this cohort there was not a unidirectional change in body weight, fat mass, or girths.

Thigh girth decline was lessened by increasing or maintaining physical activity over the follow-up period, consistent with an attenuation of muscle atrophy in response to increased physical activity. Current dogma suggests that muscle loss with advancing age may only be attenuated through resistance-type exercise. Our data suggest that increases in primarily aerobic types of physical activity may also contribute to this attenuation over a 10-y period.

The present study represents a comprehensive assessment of body-composition changes in the elderly measured by the use of whole-body and regional techniques. Several limitations should be considered, however. The error associated with body-composition assessment is well documented. The present data, however, which were collected over >10 y, were collected by the same investigator using the same equipment at both time points. Because we expected the various skinfold sites to be correlated within persons, we presented the raw correlations for our readers to evaluate. We did not perform a Bonferroni correction on the univariate correlation between change in body fat and change in various anthropometric measures because our hypothesis was that fat would be redistributed away from the subcutaneous compartment. Assessment of physical activity by questionnaire identified extremely varied patterns, intensities, and duration of physical activity at 2 points in time. It also identified physical activity over the past year so as to include seasonal activities that are important in overall health and energy balance and, as we have shown in this article, body-composition changes. Although we are fully aware of the limitations, the use of a questionnaire to assess this complex behavior has been widely validated against measures of physical fitness, and physical activity as assessed by questionnaire is significantly related to mortality and many chronic diseases. Self-report is the only way to estimate physical activity in a large group of subjects living freely in their native environments over an extended period of time. Other methods do not distinguish between the types and intensities of physical activity performed. Finally, although regional changes in body composition by CT were obtained in only a small subset of subjects, we feel that these data are valuable and can shed light on the interpretation of our data.

Waist-to-thigh ratio should be investigated further as a simple screening tool because it measures both the increase in abdominal fat, which is associated with a metabolic risk factor profile and is a predictor of late-life disability, and sarcopenia, which signals functional decline. These girth measures, or their ratio, may be helpful in identifying body-composition correlates of functional decline or disability in the aging population. Understanding the regional age-associated differences in fat redistribution and the metabolic correlates and factors that can modify these changes in an aging population will increase our ability to develop strategies to improve body-composition profiles in the middle-aged and the elderly. 

VAH and MAFS were responsible for the design, data analysis, and interpretation; VAH and MW were responsible for the data collection, quality control, and oversight of the study; MAFS and RR were responsible for securing funding for this study; WRF, RR, and WJE were responsible for data interpretation and advice on manuscript preparation; and VAH was responsible for writing the manuscript. None of the authors had any financial or

personal interest in any company or organization sponsoring the research. RR became an employee of Millennium Pharmaceuticals Inc, Cambridge, MA, after these data were collected and analyzed.

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