

Appendicular skeletal muscle mass: effects of age, gender, and ethnicity

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Gallagher, Dympna, Marjolein Visser, Ronald E. De Meersman, Dennis Sepúlveda, Richard N. Baumgartner, Richard N. Pierson, Tamara Harris, and Steven B. Heymsfield. Appendicular skeletal muscle mass: effects of age, gender, and ethnicity. *J. Appl. Physiol.* 83(1): 229–239, 1997.—This study tested the hypothesis that skeletal muscle mass is reduced in elderly women and men after adjustment first for stature and body weight. The hypothesis was evaluated by estimating appendicular skeletal muscle mass with dual-energy X-ray absorptiometry in a healthy adult cohort. A second purpose was to test the hypothesis that whole body ⁴⁰K counting-derived total body potassium (TBK) is a reliable indirect measure of skeletal muscle mass. The independent effects on both appendicular skeletal muscle and TBK of gender ($n = 148$ women and 136 men) and ethnicity ($n = 152$ African-Americans and 132 Caucasians) were also explored. Main findings were 1) for both appendicular skeletal muscle mass (total, leg, and arm) and TBK, age was an independent determinant after adjustment first by stepwise multiple regression for stature and weight (multiple regression model $r^2 = \sim 0.60$); absolute decrease with greater age in men was almost double that in women; significantly larger absolute amounts were observed in men and African-Americans after adjustment first for stature, weight, and age; and >80% of within-gender or -ethnic group between-individual component variation was explained by stature, weight, age, gender, and ethnicity differences; and 2) most of between-individual TBK variation could be explained by total appendicular skeletal muscle ($r^2 = 0.865$), whereas age, gender, and ethnicity were small but significant additional covariates (total $r^2 = 0.903$). Our study supports the hypotheses that skeletal muscle is reduced in the elderly and that TBK provides a reasonable indirect assessment of skeletal muscle mass. These findings provide a foundation for investigating skeletal muscle mass in a wide range of health-related conditions.

body composition; total body potassium; aging

AGING IN BOTH ANIMALS AND HUMANS is associated with a loss of skeletal muscle mass and a decline in muscle function (3, 32). Skeletal muscle atrophy and functional impairment with senescence in humans may be associated with osteoporotic fractures (28), the prolonged disability that accompanies hospitalizations for acute illness, falls with subsequent injury, and the frailty with inactivity often observed in geriatric populations (13).

Although skeletal muscle loss with aging in humans is well documented, several unresolved questions re-

main that relate to the magnitude of loss and whether gender and ethnic differences exist in the age-associated muscle decline. The first concern is that earlier investigations of skeletal muscle in humans were based largely on methods of questionable validity (14, 33). Two such methods, urinary creatinine excretion and total body potassium (TBK), assume that muscle is the sole or main source of intracellular creatine (30) and potassium (31), respectively. Recent studies challenge these assumptions (14, 33) and raise concerns related to the use of these methods in estimating age-related muscle loss.

An attempt was made to improve the use of TBK as a marker of skeletal muscle by devising a two-compartment method based on TBK and total body nitrogen (TBN) (5). This method assumes that the TBK-to-TBN ratios in skeletal muscle and nonskeletal muscle lean tissues are known and constant (6). A recent study suggests, however, that skeletal muscle mass estimates derived from the TBK-TBN method are substantially lower than that observed by using whole body multislice computerized tomography (33).

Much of the present understanding of skeletal muscle mass and aging is based on studies of urinary creatinine (33) and TBK (10, 22, 23) in adult populations. Questions surrounding the validity of these methods in accurately quantifying skeletal muscle mass raise concerns about the interpretation of earlier studies of skeletal muscle in relation to aging, gender, and ethnicity.

A second limitation associated with earlier investigations of changes in skeletal muscle mass with aging is the inadequate control of factors known to influence muscle, such as body weight and stature. Older subjects in some studies were shorter and weighed more or less than their younger counterparts (7, 22, 23). The independent influence of these important factors on skeletal muscle mass is usually not considered, and the prevailing hypothesis is that skeletal muscle mass is relatively reduced in the elderly. A related concern is that little is known about how women and men compare across the age span with regard to loss in muscle mass. Women on average weigh less and are shorter than men (19), and, in most previous studies, between-gender comparisons of skeletal muscle did not adequately control for body weight, stature, and age differences (7).

The third concern is that much of what is documented about skeletal muscle mass was derived from persons of Caucasian ethnicity, and there is relatively little information available on other ethnic groups. African-Americans may have different total amounts of skeletal muscle at any given age compared with Caucasian subjects (12, 21), and there may be ethnic differences in the relative loss of skeletal muscle with aging as there are with bone mineral (20).

The recent introduction of dual-energy X-ray absorptiometry (DEXA) provides a new opportunity to study the appendicular portion of skeletal muscle mass *in vivo*. Appendicular skeletal muscle accounts for >75% of total body skeletal muscle (31) and is the primary portion of skeletal muscle involved in ambulation and physical activities. Earlier studies from our laboratory (15, 33) and from other research groups (17) support the validity of DEXA estimates of appendicular skeletal muscle. An important advantage of DEXA over previous skeletal muscle mass-measuring methods is its capability of providing separate estimates of lower and upper extremity appendicular muscle components (17).

The primary purpose of this study was to test the hypothesis that skeletal muscle is reduced in the elderly after appropriate control for body weight and stature. A second study aim was to test the hypothesis that TBK reliably represents skeletal muscle mass.

METHODS

Study Design

We carried out the first purpose of this study by examining the independent effect of age on DEXA-measured appendicular skeletal muscle mass (total, leg, and arm) in a cross-sectional cohort after controlling first for stature and body weight. We also explored the independent effects on appendicular skeletal muscle of gender and ethnicity (African-American and Caucasian) after controlling first for stature, body weight, and age.

Examination of TBK was intended to bridge the many earlier studies of skeletal muscle based on TBK to the present research effort. The analysis was carried out in two stages. First, we examined the independent effect of age on TBK in the cross-sectional cohort after controlling first for stature and body weight. The independent effects on TBK of gender and ethnicity were also examined as they were for appendicular skeletal muscle mass. In the second stage of analysis, we established in our cohort how much of the observed variation in TBK could be explained by total appendicular skeletal muscle (TASM) mass and other potential independent TBK determinants such as age, gender, and ethnicity.

Subjects

Subjects were 148 women (80 African-American and 68 Caucasian) and 136 men (72 African-American and 64 Caucasian) with a body mass index (BMI; kg/m^2) <36 who had participated in an ongoing multiethnic body composition investigation (11). Race was determined by self-report. All parents and grandparents were required to be non-Hispanic African-American and non-Hispanic Caucasian, for African-American and Caucasian subjects, respectively. Recruitment of subjects occurred over a 3-yr period through advertisements in local newspapers, on radio stations, and in flyers posted in the local community. Inclusion criteria required

that subjects be ambulatory, nonvigorously exercising, with no orthopedic problems that could potentially affect any of the variables under investigation. Each subject completed a medical examination that included screening blood tests after an overnight fast. Only healthy subjects, without any diagnosed medical conditions, were enrolled in the study. The study was approved by the Institutional Review Board of St. Luke's-Roosevelt Hospital, and all subjects gave written consent to participate.

Body Composition

Appendicular skeletal muscle. Body weight was measured to the nearest 0.1 kg (Weight Tronix, New York, NY) and height to the nearest 0.5 cm by using a stadiometer (Holtain; Crosswell, Wales).

Total body fat, fat-free body mass, and TASM were measured with whole body DEXA (DPX, Lunar Radiation, Madison, WI). Software version 3.4 was used to analyze all of the DEXA scans. The calculation of appendicular skeletal muscle mass has been previously described in detail (15). With the use of specific anatomic landmarks, the legs and arms are isolated on the skeletal X-ray planogram (anterior view). The arm encompasses all soft tissue extending from the center of the arm socket to the phalange tips, and contact with the ribs, pelvis, or greater trochanter is avoided. The leg consists of all soft tissue extending from an angled line drawn through the femoral neck to the phalange tips. The system software provides the total mass, ratio of soft tissue attenuations, and bone mineral mass for the isolated regions. The ratio of soft tissue attenuation for each region was used to divide bone mineral-free tissue of the extremities into fat and fat-free components. The fat and bone mineral-free portion of the extremities were assumed to represent appendicular skeletal muscle mass along with a small and relatively constant amount of skin and underlying connective tissues.

Leg skeletal muscle (LSM) mass and arm skeletal muscle (ASM) mass represent the sum of both right and left extremities, respectively. TASM was taken as the combined sum of LSM and ASM. Repeated daily measurements over 5 days in four subjects showed a coefficient of variation (CV; means \pm SD) of $2.4 \pm 0.5\%$ for LSM, $7.0 \pm 2.4\%$ for ASM, and $3.0 \pm 1.5\%$ for TASM.

Earlier studies indicate that African-American subjects have significantly greater skeletal muscle mass (12) and longer appendicular bone lengths (1, 12, 21) compared with Caucasian subjects. The possibility therefore exists that longer extremities in African-American subjects might explain their greater appendicular skeletal muscle mass after adjustment for covariates such as height, weight, age, and gender. We therefore also included in our multiple-regression models measurements of appendicular bone lengths. The skeletal X-ray planogram generated by the DEXA scan was used specifically to measure tibia length, femur length, humerus length, and total subject skeletal lengths. All dimensions were measured in millimeters by a single reader by using an engineering caliper (Staedtler, Frankfurt, Germany). Total skeletal length was measured as the distance from the apex of the cranium to the plantar surface of the calcaneus bone. Appendicular bone lengths were measured from the proximal to the distal end of the bones; tibia length from the lateral condyle to the medial malleolus; femoral length from the greater trochanter to the lateral epicondyle; and humerus length from the greater tubercle to the lateral epicondyle. These dimensions do not correspond precisely to anatomic bone lengths, although all measurements were consistent among subjects. The ratio of tibia plus femur length to total subject skeletal length was used as an index of relative leg

Table 1. Baseline subject characteristics

	Women		Men	
	African-American	Caucasian	African-American	Caucasian
<i>n</i>	80	68	72	64
Age, yr	51.8 ± 15.7	46.0 ± 18.8*	49.9 ± 15.3	41.5 ± 20.4†
Body wt, kg	72.5 ± 12.7	64.9 ± 11.9‡	79.7 ± 11.2	78.6 ± 11.4
Height, m	1.62 ± 0.06	1.63 ± 0.06	1.74 ± 0.06	1.77 ± 0.07*
Body mass index, kg/m ²	27.5 ± 4.4	24.6 ± 4.7‡	26.1 ± 3.1	25.2 ± 3.4
Body fat, %	36.0 ± 8.0	33.3 ± 9.3†	22.5 ± 7.2	21.1 ± 8.8
Fat-free body mass, kg	44.9 ± 5.5	42.7 ± 5.2†	61.4 ± 8.2	61.5 ± 7.5
Total body potassium, meq	2,487 ± 394	2,357 ± 333*	3,734 ± 628	3,796 ± 527
Appendicular skeletal muscle, kg				
Total	20.5 ± 2.8	18.6 ± 2.6‡	29.4 ± 4.4	28.3 ± 3.9
Leg	15.6 ± 2.0	14.5 ± 1.9‡	21.7 ± 3.4	21.1 ± 2.8
Arm	4.9 ± 1.1	4.1 ± 1.0‡	7.7 ± 1.4	7.2 ± 1.5*
Leg/arm	3.30 ± 0.56	3.68 ± 0.57‡	2.86 ± 0.36	3.02 ± 0.47†
Leg bone length/ht	0.499 ± 0.018	0.485 ± 0.021‡	0.500 ± 0.019	0.485 ± 0.021‡
Arm bone length/ht	0.183 ± 0.014	0.184 ± 0.013	0.173 ± 0.011	0.169 ± 0.012*

Values are means ± SD; *n*, no. of subjects. * $P < 0.05$, † $P < 0.01$, ‡ $P < 0.001$ for African-American vs. Caucasian subjects.

length. The ratio of humerus length to total subject skeletal length was used as an index of relative arm length.

TBK

The St. Luke's 4- π whole body counter was used to measure ⁴⁰K (25). The ⁴⁰K raw counts accumulated over 9 min were adjusted for body size on the basis of a ⁴²K calibration equation (26). The within-subject CV in our laboratory for ⁴⁰K counting is 4% (26). TBK was calculated as TBK (mmol) = ⁴⁰K (mmol)/0.0118.

Statistical Analysis

Data were analyzed by using the Statistical Analysis System (SAS; release 6.10, SAS Institute, Cary, NC). Differences between ethnic groups were tested by using Student's *t*-tests. Pearson's correlation coefficients were used to establish the univariate relationships between total and regional skeletal muscle mass and age. Pearson's correlation coefficients adjusted for age were used to establish the relationships between total and regional skeletal muscle mass and other body composition components, as well as subject demographic characteristics. The relationships between skeletal muscle measurements and height, weight, age, and ethnicity were investigated by using multiple-regression analysis. TASM, LSM, and ASM were used as dependent variables and height, weight, age, ethnicity, and extremity lengths were used as independent variables in the multiple-regression models. In addition, potential interaction terms and nonlinear relationships were explored for selected variables. Statistical significance was set at $P < 0.05$ by using a two-sided P value. Group subject data are expressed as means ± SD.

RESULTS

Baseline Characteristics

The baseline subject characteristics are summarized in Table 1. The African-American women as a group were older ($P = 0.04$), weighed more ($P = 0.0003$), and had a higher BMI ($P = 0.0001$) compared with the Caucasian women. There were no significant differences in height between African-American and Caucasian women. Relative leg length was significantly ($P = 0.0001$) greater in African-American women compared with their Caucasian counterparts.

African-American men were, on average, older ($P = 0.009$) and shorter ($P = 0.05$) compared with Caucasian men. There were no significant differences between the two groups of men in body weight and BMI. African-American men had relatively longer legs ($P < 0.0001$) compared with Caucasian men.

Age-Adjusted Appendicular Skeletal Muscle Associations

There were significant negative correlations between most of the appendicular skeletal muscle components and age in all four groups (Table 2). After adjustment for the effects of age, TASM mass, LSM, and ASM were all significantly and positively correlated with body weight (all $P = 0.001$) and fat-free body mass (all $P = 0.001$) in African-American and Caucasian women and men. TASM and LSM were also positively correlated

Table 2. Appendicular skeletal muscle mass univariate and age-adjusted correlations

	Women		Men	
	African-American	Caucasian	African-American	Caucasian
TASM vs.				
Age	-0.37‡	-0.43‡	-0.31†	-0.52‡
Body wt	0.72‡	0.71‡	0.75‡	0.60‡
Ht	0.64‡	0.53‡	0.65‡	0.44‡
FFM	0.81‡	0.80‡	0.86‡	0.74‡
TBK	0.75‡	0.63‡	0.86‡	0.80‡
LSM vs.				
Age	-0.42‡	-0.47‡	-0.33†	-0.48‡
Body wt	0.53‡	0.51‡	0.70‡	0.50‡
Ht	0.68‡	0.60‡	0.64‡	0.57‡
FFM	0.66‡	0.69‡	0.81‡	0.63‡
ASM vs.				
Age	-0.17	-0.23	-0.22	-0.46‡
Body wt	0.81‡	0.87‡	0.71‡	0.55‡
Ht	0.39‡	0.28*	0.51‡	0.04
FFM	0.83‡	0.78‡	0.78‡	0.68‡
Leg muscle	0.56‡	0.61‡	0.70‡	0.48‡

TASM, LSM, and ASM: total, leg, and arm appendicular skeletal muscle, respectively; FFM, fat-free mass; TBK, total body potassium. * $P < 0.05$; † $P < 0.01$; ‡ $P < 0.001$.

Table 3. TASM mass multiple-regression analysis models

	Regression Coefficient							
	Ht	Body Wt	Age	Gender ^e	Ethnicity ^f	Intercept	r ²	SEE
Women								
African-American	18.37 ± 3.60 ^{c,d}	0.10 ± 0.02 ^c	-0.04 ± 0.01 ^b			-15.02 ± 5.75 ^a	0.67	1.61
Caucasian	17.30 ± 3.07 ^c	0.13 ± 0.01 ^c	-0.04 ± 0.01 ^c			-15.94 ± 5.15 ^b	0.73	1.40
Men								
African-American	24.62 ± 6.66 ^c	0.22 ± 0.03 ^c	-0.06 ± 0.02 ^b			-27.56 ± 10.78 ^a	0.67	2.60
Caucasian	11.88 ± 5.80 ^a	0.16 ± 0.03 ^c	-0.09 ± 0.02 ^c			-1.08 ± 9.82	0.58	2.58
African-Americans	22.02 ± 3.79 ^c	0.15 ± 0.02 ^c	-0.05 ± 0.01 ^c	5.05 ± 0.55 ^c		-23.59 ± 5.92 ^c	0.85	2.26
Caucasians	14.35 ± 3.24 ^c	0.14 ± 0.02 ^c	-0.07 ± 0.01 ^c	5.46 ± 0.56 ^c		-10.64 ± 5.29 ^a	0.88	2.09
Women	17.52 ± 2.34 ^c	0.11 ± 0.01 ^c	-0.04 ± 0.01 ^c		1.35 ± 0.26 ^c	-15.62 ± 3.83 ^c	0.73	1.51
Men	18.16 ± 4.44 ^c	0.19 ± 0.02 ^c	-0.08 ± 0.01 ^c		2.01 ± 0.47 ^c	-15.32 ± 7.39 ^a	0.62	2.64

Values are means ± SD; $n = 80$ African-American and 68 Caucasian women and 72 and 64 African-American and Caucasian men, respectively. r^2 , explained variance; SEE, SE of estimate. ^a $P < 0.05$; ^b $P < 0.01$; ^c $P < 0.001$; ^destimate of regression coefficient ± SEE; ^e and ^f, dummy codes are 0 and 1 for female and male and 0 and 1 for Caucasian and African-American subjects, respectively.

with height ($P = 0.001$) in African-American and Caucasian women and men. ASM mass was positively correlated with height in African-American women and men ($P = 0.001$) and in Caucasian women ($P = 0.005$).

TASM and LSM were negatively associated with age in African-American ($P = 0.01$) and Caucasian ($P = 0.001$) women and men. ASM was negatively associated with age in Caucasian men ($P = 0.0002$) only.

TBK was also negatively associated with age in both African-American ($P = 0.001$) and Caucasian women ($P = 0.01$) and men ($P = 0.001$). After adjustment for the effects of age, TBK was positively correlated with TASM ($P = 0.001$) in all four subgroups.

Appendicular Skeletal Muscle Mass Models

In each of the following sections we develop appendicular skeletal muscle mass (TASM, LSM, and ASM) multiple-regression models. A composite analysis section is then provided that summarizes the salient features of the three appendicular skeletal muscle multiple regression models.

TASM mass. TASM mass multiple-regression models for the four subgroups (African-American women and men; Caucasian women and men) and two combined groups (total women and men; total African-American and Caucasian subjects) are presented in Table 3. These models explore the independent effects on TASM of height, weight, age, gender, and ethnicity.

HEIGHT AND WEIGHT. With the use of stepwise multiple-regression analyses to predict TASM, height and body weight entered first into the model in all four subgroups. Height and weight explained 64 and 67% of the TASM variance in African-American and Caucasian women and 63 and 39% in African-American and Caucasian men, respectively. Both height² and weight² failed to contribute to the model, suggesting a linear relationship between TASM and both weight and height.

AGE. In all four subgroups, age contributed significantly to the multiple-regression model, explaining an additional 3 and 6% of the variance in TASM in African-American and Caucasian women, respectively, and 4 and 19% in African-American and Caucasian men, respectively. The interaction terms weight × age

and age² failed to significantly contribute to the model, thereby suggesting that the decline in TASM with increasing age is linear (Fig. 1) and independent of body weight.

GENDER. After adjustment for height, body weight, and age, men had larger TASM compared with women in both African-American and Caucasian subjects ($P = 0.0001$) across the entire age range studied. The interaction term age × gender contributed significantly to the model containing height, body weight, and age in Caucasian subjects ($P = 0.02$), suggesting that the decrease in TASM with greater age is larger in men than in women. The age × gender interaction was of borderline significance ($P = 0.13$) in African-American subjects.

ETHNICITY. After adjustment for height, body weight, age, and gender, African-American women and men had greater TASM compared with Caucasian women and men (both $P = 0.0001$). The lower TASM with greater age was, however, not significantly different among African-American and Caucasian women ($P = 0.94$) and men ($P = 0.52$).

LSM mass. LSM mass multiple-regression models for the subgroups and combined groups are presented in

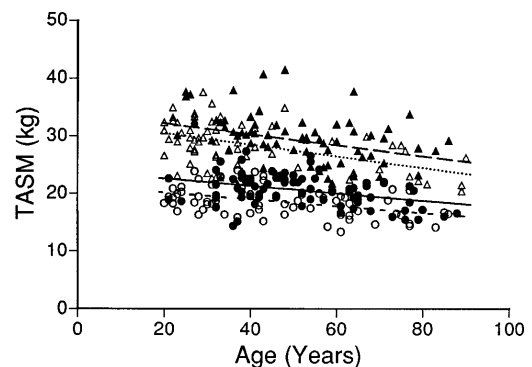


Fig. 1. Total appendicular skeletal muscle (TASM) vs. age in Caucasian women (CW; ○), African-American women (AAW; ●), Caucasian men (CM; △), and African-American men (AA; ▲). Linear regression lines (top to bottom): dashed line, AA; dotted line, CM; solid line, AAW; dashed line, CW. CW: TASM = -0.06 (age) + 21.37 kg, $r = 0.43$, $n = 68$. AAW: TASM = -0.07 (age) + 23.87 kg, $r = 0.37$, $n = 80$. CM: TASM = -0.10 (age) + 32.52 kg, $r = 0.52$, $n = 64$. AAM: TASM = -0.10 (age) + 32.07 kg, $r = 0.33$, $n = 72$.

Table 4. *LSM mass multiple-regression analysis models*

	Regression Coefficient							
	Ht	Body wt	Age	Gender ^e	Ethnicity ^f	Intercept	r ²	SEE
Women								
African-American	17.94 ± 2.89 ^{c,d}	0.04 ± 0.01 ^b	-0.02 ± 0.01 ^a			-14.96 ± 4.61 ^b	0.60	1.29
Caucasian	15.37 ± 2.61 ^c	0.06 ± 0.01 ^c	-0.03 ± 0.01 ^b			-13.07 ± 4.38 ^b	0.63	1.19
Men								
African-American	21.17 ± 5.34 ^c	0.14 ± 0.03 ^c	-0.05 ± 0.02 ^b			-24.08 ± 8.65 ^b	0.63	2.09
Caucasian	17.28 ± 4.28 ^c	0.07 ± 0.02 ^b	-0.05 ± 0.01 ^c			-13.13 ± 7.24	0.56	1.90
African-Americans	20.22 ± 3.07 ^c	0.08 ± 0.01 ^c	-0.03 ± 0.01 ^b	2.99 ± 0.44 ^c		-21.13 ± 4.80 ^c	0.80	1.83
Caucasians	16.21 ± 2.45 ^c	0.07 ± 0.01 ^c	-0.04 ± 0.01 ^c	3.24 ± 0.42 ^c		-14.38 ± 4.0 ^c	0.85	1.58
Women	16.36 ± 1.92 ^c	0.05 ± 0.01 ^c	-0.03 ± 0.01 ^c		0.95 ± 0.22 ^c	-14.04 ± 3.15 ^c	0.64	1.24
Men	19.52 ± 3.42 ^c	0.11 ± 0.02 ^c	-0.05 ± 0.01 ^c		1.31 ± 0.36 ^c	-19.88 ± 5.69 ^c	0.59	2.03

Values are means ± SD; n = 80 African-American and 68 Caucasian women and 72 and 64 African-American and Caucasian men, respectively. ^aP < 0.05; ^bP < 0.01; ^cP < 0.001; ^destimate of regression coefficient ± SEE; ^e and ^f, dummy codes are 0 and 1 for female and male and 0 and 1 for Caucasian and African-American subjects, respectively.

Table 4. These models explore the independent effects on LSM of height, weight, age, gender, and ethnicity.

HEIGHT AND WEIGHT. Height and weight explained 57 and 58% of LSM variance in African-American and Caucasian women and 59 and 45% in African-American and Caucasian men, respectively.

AGE. After height and weight, age contributed to the model in all four subgroups. Age explained an additional 3 and 5% of the LSM variance in African-American and Caucasian women and 4 and 11% in African-American and Caucasian men, respectively. Age failed to interact with height or weight in African-American and Caucasian men and Caucasian women, suggesting that the lower LSM with greater age (Fig. 2) is independent of height or weight.

GENDER. In African-American and Caucasian subjects, men had greater LSM compared with women (P = 0.0001), independent of height, weight, and age. Gender tended to interact with age in Caucasian (P = 0.09) and African-American subjects (P = 0.15), suggesting a greater magnitude reduction in LSM with older age in men compared with women.

ETHNICITY AND LOWER LIMB LENGTHS. After adjustment for height, body weight, and age, African-American subjects had more LSM than Caucasian subjects (women, P = 0.0001; men, P = 0.0004).

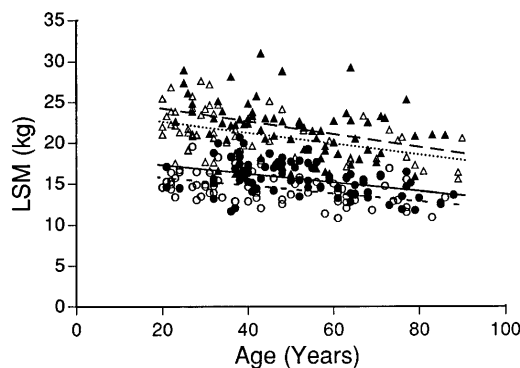


Fig. 2. Leg skeletal muscle (LSM) vs. age in CW, AAW, CM, and AAM. Symbols and lines are defined as in Fig. 1. CW: LSM = -0.05 (age) + 16.75 kg, r = 0.48, n = 68. AAW: LSM = -0.05 (age) + 18.38 kg, r = 0.42, n = 80. CM: LSM = -0.07 (age) + 23.92 kg, r = 0.48, n = 64. AAM: LSM = -0.08 (age) + 25.79 kg, r = 0.33, n = 72.

Relative leg length alone was significantly correlated with LSM in women (r = 0.30, P < 0.001), and this association was of borderline significance (r = 0.14, P < 0.10) in men. When relative leg length was added to the multiple-regression model, it contributed significantly (P = 0.02) in men. African-American men thus had greater LSM than Caucasian men (P = 0.0034) after adjustment for ethnic differences in lower limb length.

The decrease in LSM with greater age was similar in African-American and Caucasian men and women.

ASM mass. ASM mass multiple-regression models for the subgroups and combined groups are presented in Table 5. The models presented explore the independent effects on ASM of height, weight, age, gender, and ethnicity.

HEIGHT, WEIGHT, AND AGE. Body weight entered first into the ASM regression model. In contrast to TASM and LSM, height did not contribute significantly to the model. Body weight alone explained 63 and 66% of the variance in African-American and Caucasian women, and 47 and 24% in African-American and Caucasian men, respectively. After adjustment for body weight, age contributed significantly to the model in all four subgroups. Age failed to interact with weight in the model, suggesting that the decline in ASM with increasing age (Fig. 3) is independent of weight.

GENDER. After adjustment for body weight and age, men had more ASM compared with women in both ethnic groups (P = 0.0001). In Caucasian subjects the interaction term gender × age was significant (P = 0.005), once again suggesting a larger magnitude decrease in muscle mass with greater age in Caucasian men compared with Caucasian women (Fig. 3). The age-gender interaction term was not statistically significant in African-American subjects.

ETHNICITY AND ARM LENGTH. After adjustment for body weight and age, African-American women and men had significantly more ASM than did Caucasian subjects.

Relative arm length alone was not significantly correlated with ASM in either women or men. Relative arm length contributed significantly to the multiple regression model in women (P = 0.03) and was of borderline significance in men (P = 0.07). That is, ethnic differences in ASM were still apparent in women and men

Table 5. ASM mass multiple-regression analysis models

	Regression Coefficient						
	Body Wt	Age	Sex ^e	Ethnicity ^f	Intercept	r ²	SEE
Women							
African-American	0.07 ± 0.01 ^{c,d}	-0.01 ± 0.00 ^b			0.61 ± 0.48	0.66	0.63
Caucasian	0.07 ± 0.01 ^c	-0.02 ± 0.00 ^c			0.30 ± 0.36	0.75	0.50
Men							
African-American	0.08 ± 0.01 ^c	-0.02 ± 0.01 ^a			1.96 ± 0.92 ^a	0.51	0.98
Caucasian	0.07 ± 0.01 ^c	-0.04 ± 0.01 ^c			3.17 ± 0.99 ^b	0.49	1.10
African-Americans	0.07 ± 0.01 ^c	-0.02 ± 0.00 ^c	2.25 ± 0.14 ^c		0.29 ± 0.47	0.81	0.82
Caucasians	0.07 ± 0.01 ^c	-0.03 ± 0.00 ^c	2.02 ± 0.18 ^c		0.77 ± 0.46	0.82	0.86
Women	0.07 ± 0.00 ^c	-0.01 ± 0.01 ^c		0.39 ± 0.10 ^c	0.28 ± 0.28	0.74	0.57
Men	0.08 ± 0.01 ^c	-0.03 ± 0.01 ^c		0.72 ± 0.18 ^c	2.36 ± 0.67 ^c	0.50	1.04

Values are means ± SD; $n = 80$ African-American and 68 Caucasian women and 72 and 64 African-American and Caucasian men, respectively. ^a $P < 0.05$; ^b $P < 0.01$; ^c $P < 0.001$; ^destimate of regression coefficient ± SEE; ^e and ^f, dummy codes are 0 and 1 for female and male and 0 and 1 for Caucasian and African-American subjects, respectively.

after adjustment for relative arm length, with African-American subjects having more ASM compared with Caucasian subjects.

The decrease in ASM with greater age was not significantly different between African-American and Caucasian women ($P = 0.59$).

Composite summary. For TASM and LSM, height, body weight, age, gender, and ethnicity each contributed independently to the respective multiple-regression models. ASM was similar, except that height did not contribute significantly to the models. After adjustment for height and body weight, men had greater TASM, LSM, and ASM (all $P = 0.001$) than women across the entire age span. Within each ethnic group, height, body weight, age, and gender accounted for 80–88% of between-subject differences in appendicular skeletal muscle.

African-American subjects had greater TASM, LSM, and ASM than Caucasian subjects of equivalent height, body weight, age, and gender. This is shown for the hypothetical Reference Woman and Reference Man (see Table 7). The table provides appendicular skeletal muscle mass estimates for subjects ages 20–70 yr on the basis of data presented in Tables 3–5. After adjustment for height (TASM and LSM only), weight, and age, 20-yr-old African-American women have ~1.4

(7.3%), 1.0 (6.3%), and 0.4 kg (9.6%) more TASM, LSM, and ASM, respectively, than their Caucasian counterparts. Similarly, African-American men have 2.0 (7.4%), 1.3 (6.6%), and 0.72 kg (9.8%) more TASM, LSM, and ASM, respectively, than Caucasian men. The ethnic differences in appendicular skeletal muscle mass persisted even after adjustment for the significantly longer appendicular lengths in African-American subjects.

The age-term slopes in multiple-regression appendicular skeletal muscle mass models were all greater in men (–0.08, –0.05, and –0.03 kg/yr for TASM, LSM, and ASM, respectively) than in women (–0.04, –0.03, and –0.01 kg/yr) (see Table 7). The Reference Woman would have a 2.0 kg or ~10.8% (in both ethnic groups) decrease in appendicular skeletal muscle between the ages of 20 and 70 yr. The decrease in TASM between the ages of 20 and 70 yr for the Reference Man is 4.0 kg or ~14.7%. The absolute decrease in appendicular skeletal muscle mass with greater age is thus larger in men than in women, whereas, in relative terms, the gender differences persisted but were smaller in magnitude.

The multiple-regression models also suggest a gender difference in skeletal muscle distribution. This observation is evident in the appendicular skeletal muscle mass estimates for the Reference Woman and Reference Man (see Table 7). LSM is ~80 and 73% of TASM in women and men, respectively. The ratio of LSM to ASM for the Reference Woman and Reference Man is ~3.6 and ~2.6, respectively. Accordingly, it would appear that women have a larger proportion of their appendicular skeletal muscle located in the lower extremities than men.

TBK Models

The TBK multiple regression models for the subgroups and combined groups are shown in Table 6. The models presented explore the independent effects on TBK of height, weight, age, gender, and ethnicity.

Height and weight. In all four subgroups, height entered first into the multiple-regression model, accounting for 28–42% of the variance in TBK. In African-American men, body weight increased the explained

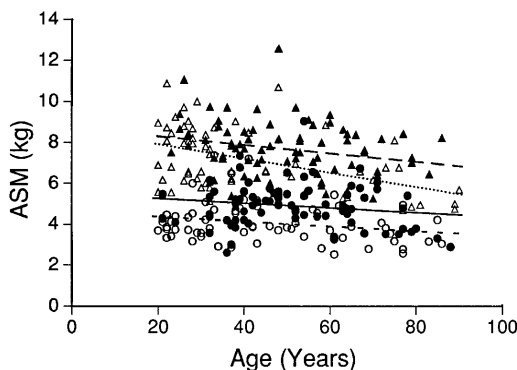


Fig. 3. Arm skeletal muscle (ASM) vs. age in CW, AAW, CM, and AAM. Symbols and lines are defined as in Fig. 1. CW: ASM = –0.01 (age) + 4.61 kg, $r = 0.23$, $n = 68$. AAW: ASM = –0.01 (age) + 5.50 kg, $r = 0.53$, $n = 80$. CM: ASM = –0.04 (age) + 8.61 kg, $r = 0.46$, $n = 64$. AAM: ASM = –0.02 (age) + 8.72 kg, $r = 0.23$, $n = 72$.

Table 6. TBK multiple-regression models

	Regression Coefficient							
	Ht	Body wt	Age	Sex ^d	Ethnicity ^e	Intercept	r ²	SEE
Women								
African-American	2,848 ± 588 ^{b,c}		-8.91 ± 2.31 ^b			-1,675 ± 1,010	0.46	293
Caucasian	2,256 ± 560 ^b		-5.51 ± 1.92 ^a			-1,060 ± 957	0.43	254
Men								
African-American	2,086 ± 1,019 ^a	22.5 ± 5.1 ^b	-17.65 ± 3.24 ^b			-2,557 ± 1,655	0.63	393
Caucasian	2,810 ± 795 ^b		-13.10 ± 2.50 ^b			-607 ± 1,443	0.52	373
African-Americans	2,602 ± 608 ^b	13.23 ± 2.84 ^b	-13.40 ± 2.07 ^b	819 ± 88 ^b		-2,007 ± 951	0.81	359
Caucasians	1,939 ± 499 ^b	8.25 ± 2.58 ^a	-10.63 ± 1.60 ^b	1,029 ± 87 ^b		-846 ± 814	0.87	314
Women	2,160 ± 426 ^b	5.59 ± 1.94 ^a	-7.77 ± 1.50 ^b		137 ± 49 ^a	-1,162 ± 696	0.49	271
Men	2,346 ± 651 ^b	19.85 ± 3.44 ^b	-16.24 ± 1.99 ^b		73 ± 69	-1,198 ± 1,079	0.62	374

Values are means ± SD; $n = 80$ African-American and 68 Caucasian women and 72 and 64 African-American and Caucasian men, respectively. ^a $P < 0.01$; ^b $P < 0.001$; ^cestimate of regression coefficient ± SEE; ^d and ^e, dummy codes are 0 and 1 for female and male and 0 and 1 for Caucasian and African-American subjects, respectively.

variance by 7%. Body weight did not contribute significantly to the model in the remaining three groups.

Age. Age contributed significantly to the models in all four subgroups. The lower TBK with greater age (Fig. 4) was independent of height or body weight, except in African-American men, in whom there was a negative interaction term (weight × age; $P = 0.02$), suggesting that men with a relatively higher body weight have a smaller magnitude decrease in TBK with greater age.

Gender. Men had relatively more TBK than women in both African-American and Caucasian subjects ($P = 0.0001$). The interaction term gender × age contributed significantly to the regression model in both African-American ($P = 0.020$) and Caucasian ($P = 0.004$) subjects, indicating a larger reduction in TBK with greater age in men compared with women.

Ethnicity. A significant ethnic difference in TBK, after adjustments for other covariates, was apparent in women ($P = 0.0053$). According to the model, African-American women had a larger TBK compared with Caucasian women. The lower TBK with greater age was similar for African-American and Caucasian women ($P = 0.12$) and men ($P = 0.34$). African-American men also had a greater TBK than Caucasian men, although the difference was not statistically significant ($P = 0.29$).

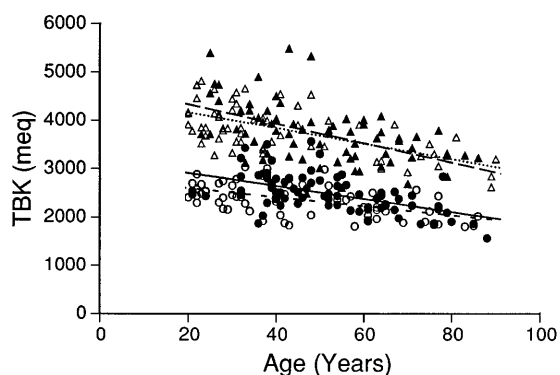


Fig. 4. Total body potassium (TBK) vs. age in CW, AAW, CM, and AAM. Symbols and lines are defined as in Fig. 1. CW: TBK = $-9.30(\text{age}) + 2,781$ meq, $r = 0.53$, $n = 68$. AAW: TBK = $-13.34(\text{age}) + 3,173$ meq, $r = 0.54$, $n = 80$. CM: TBK = $-16.23(\text{age}) + 4,487$ meq, $r = 0.63$, $n = 64$. AAM: TBK = $-20.20(\text{age}) + 4,734$ meq, $r = 0.51$, $n = 72$.

Composite summary. Unlike TASM models, the TBK models showed no significant dependency on body weight within three of the four subgroups. Like TASM models, the TBK models showed significant dependencies on age, gender, and ethnicity (women only), and the decrease in TBK with increasing age was greater in men than in women. Within each ethnic group, height, weight, age, and gender accounted for 81–87% of between-individual TBK differences.

TBK-Appendicular Skeletal Muscle Comparison

TBK was strongly correlated with TASM. For example, in all subjects combined, simple linear regression of TBK vs. TASM gave an r of 0.93 ($P < 0.001$; standard error of the estimate = 87 meq), indicating that TASM explained 86.5% of between-individual differences in TBK. Three independent variables added significantly to the model, i.e., age, gender, and ethnicity, although the increase in r (to 0.95) and explained variance (90.3%) was not very large.

DISCUSSION

The primary purpose of the present study was to quantitatively test the hypothesis that, after adjustment for stature and body weight, skeletal muscle is significantly lowered in the elderly. To accomplish this purpose and to explore other independent determinants of skeletal muscle, we developed age-, gender-, and ethnic-specific appendicular skeletal muscle mass multiple-regression models that appropriately adjust for subject height and weight.

An additional purpose was to test the hypothesis that TBK provides an indirect measurement of appendicular skeletal muscle mass in vivo. This hypothesis is based on the observation that a large proportion of TBK (~60%) is found in skeletal muscle tissue. Many earlier studies evaluated TBK as a measure of skeletal muscle mass, and our purpose in developing TBK multiple-regression models was twofold. Our first question was whether these models gave a qualitatively similar view of skeletal muscle determinants like TASM. A second, and related, concern was how comparable our TBK models were to those developed over the past four

decades in both cross-sectional and longitudinal cohorts.

Our results indicate that, after adjustment for stature and body weight, age is a significant independent determinant of appendicular skeletal muscle mass. Additionally, we found that gender and ethnicity (i.e., African-American and Caucasian) also independently determine an individual's appendicular skeletal muscle mass. A qualitatively similar pattern is observed with TBK, although our findings suggest that, to a certain extent, age, gender, and ethnicity moderate the TBK-TASM relationship.

Skeletal Muscle Mass and TBK Determinants

Height and weight. Our observations indicate that height and weight are the main determinants of appendicular skeletal muscle mass. Although there was some variation between the four subgroups, height and weight together explained almost two-thirds of between-individual variation in TASM. Height alone was a stronger determinant of TBK within each of the subgroups, explaining from one-fourth to one-half of between-individual variation.

It is reasonable that stature and appendicular skeletal muscle mass are closely related. Taller subjects with longer extremity bones would be expected to have greater muscle weights. Similarly, heavier subjects, who require greater appendicular skeletal muscle mass for extremity movement, would be expected to have more muscle than their lean counterparts. Our modeling results suggest that linear relationships exist among the mass of appendicular skeletal muscles, stature, and body weight.

Age. Our findings with respect to age were twofold: after adjustment for stature and weight within each subgroup, older subjects had less appendicular skeletal muscle than younger subjects, and, in absolute terms, the decrease in appendicular skeletal muscle mass with increasing age was greater in men than in women. These findings, in a relatively large cross-sectional cohort, corroborate a substantial body of earlier literature indicating reductions in or loss of lean body mass, fat-free body mass, and skeletal muscle as indicated by elemental analysis (TBK and/or TBN) (4, 6, 8, 10, 23), urinary creatinine excretion (10, 32), and anthropometry (26). Our findings suggest a linear decline in TASM of ~0.4 kg/decade in women and 0.8 kg/decade in men (Table 7). A significant reduction in TBK with greater age was also observed (78 and 163 meq/decade in women and men, respectively).

Linkage with earlier studies. The TBK observations are notable because a large body of earlier studies inferred an age-related loss in skeletal muscle or lean mass. Unfortunately, most of these studies did not control adequately for covariates such as stature and body weight so that quantitative estimates cannot be made for the independent effects of aging on body composition. We reasoned that the results of these earlier studies might be similar to our own, and thus findings across studies might be generalizable. To explore this possibility, we used our TBK regression

Table 7. TASM mass, LSM, and ASM in Reference Woman and Reference Man at ages 20 and 70 yr by using composite multiple-regression models

	African-American		Caucasian		Δ /Decade
	20 yr	70 yr	20 yr	70 yr	
Reference Woman					
TASM, kg	19.87	17.87	18.52	16.52	-0.40
LSM, kg	15.95	14.45	15.0	13.50	-0.30
ASM, kg	4.44	3.94	4.05	3.55	-0.10
TBK, meq	2,679	2,291	2,542	2,154	77.7
Reference Man					
TASM, kg	29.26	25.26	27.25	23.25	-0.80
LSM, kg	21.31	18.80	20.0	17.50	-0.50
ASM, kg	8.08	6.58	7.36	5.86	-0.30
TBK, meq	3,928	3,116	3,855	3,043	162.4

Δ , Change. Data for Reference Woman (wt 56.7 kg, ht 1.638 m) and Reference Man (wt 70 kg, ht 1.7 m) are on basis of correlations of multiple-regression coefficients for women and men, respectively, in Tables 2-5. In Δ /decade, regression line slope of age term $\times 10$.

models to estimate TBK on the basis of height, weight, and subject age as published in relevant earlier cross-sectional studies (Table 8). We then compared TBK estimates from our models to measured TBK in each of the studies as a means of establishing whether similar findings apply across all investigations. The earlier studies were selected from a broad body of literature extending from 1965 to the present and are intended to be representative of both American (7, 8, 22) and European (4, 23) populations on whom TBK data are available. As shown in Table 8, the observed TBK ranged from 1 to 22% and from 1 to 8% of values derived by using TBK regression models in the present study for women and men, respectively. Older persons in earlier studies had less TBK (8-33%) than younger persons, this being true for both women (8-15%) and men (17-33%). Similar consistencies were observed between studies with regard to gender differences in TBK, with men having greater absolute amounts (31-46%) compared with women.

A longitudinal study of TBK in adults (age 28-60+ yr) was carried out by Flynn et al. (9), and estimates of TBK loss per decade were provided in age and gender groupings. We pooled age subgroups in this study to form a single group of women and a similar group of men, calculating weighted baseline and 10-yr follow-up values for height, weight, age, and TBK. The results of baseline and 10-yr follow-up measured and predicted TBK are plotted along with the aforementioned cross-sectional studies in Fig. 5. Figure 5 shows remarkable concordance between cross-sectional and longitudinal studies of TBK spanning five decades, including the present investigation. That is, our TBK regression models overall gave almost identical TBK estimates to measured TBK in the respective earlier studies (4, 7, 8, 22, 23). These observations strongly support the uniformity of findings across studies and underscore the striking similarity with which adults lose potassium, and presumably mainly skeletal muscle, with advancing age.

An important question is what mechanisms are responsible for skeletal muscle mass loss with aging?

Disuse atrophy and malnutrition are important causes of muscle loss in hospitalized elderly subjects, although we eliminated subjects in the present study who were bedridden or who had physical disabilities and chronic illnesses. Additional causes of skeletal muscle loss with aging are neurogenic and hormonal (e.g., growth hormone, insulin-like growth factor I, androgens) mechanisms (16, 27, 29). The independent influence of the various processes on the rate of skeletal muscle loss with aging is an important area of future research.

Gender: Appendicular skeletal muscle mass and TBK were both greater in men than in women after adjustment for stature, weight, and age. An additional obser-

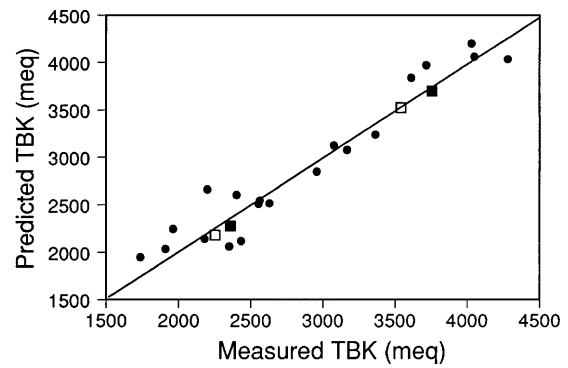


Fig. 5. Measured TBK (from selected published studies) vs. predicted TBK in adults. Predicted TBK is on basis of regression coefficients for men and women in Table 6. ●, Novak (22), Oberhausen and Onstad (23), Cohn et al. (7), Ellis (8), and Bruce et al. (4) data; ■, baseline; □, Flynn et al. (9) 12-yr follow-up data.

Table 8. Summary of previous TBK studies compared with TBK prediction models in present study

Study, Year (Ref. No.)	Observed				Predicted	
	Ht, m	Wt, kg	Age, yr	TBK, meq	TBK, meq	TBK, meq
Novak, 1972 (22)						
Women						
Younger	1.63	56.3	21	2,555	2,511	
Older	1.60	63.0	75	2,351	2,063	
Δ			54	-204	-448	
Men						
Younger	1.77	72.9	21	4,051	4,060	
Older	1.72	73.4	75	3,168	3,076	
Δ	0.05	0.5	54	-883	-984	
Oberhausen and Onstad, 1965 (23)						
Women						
Younger	1.64	64.0	25	2,564	2,544	
Older	1.60	70.0	70	2,180	2,141	
Δ			45	-384	-403	
Men						
Younger	1.75	74.0	25	3,718	3,971	
Older	1.70	74.0	70	3,077	3,122	
Δ			45	-641	-849	
Cohn et al., 1976 (7)						
Women						
Younger	1.57	55.6	33.5	1,964	2,247	
Older	1.56	57.9	72.5	1,738	1,949	
Δ			39	-226	-298	
Men						
Younger	1.74	78.0	34.7	3,615	3,840	
Older	1.70	70.0	74.5	2,402	2,604	
Δ			39.8	-1,213	-1,236	
Ellis, 1990 (8)						
Women						
Younger			22	2,200	2,660	
Older	1.62	59.2	72	1,910	2,036	
Δ	1.58	61.6	50	-290	-624	
Men						
Younger	1.78	79.9	22	4,031	4,200	
Older	1.71	76.6	73	2,959	2,848	
Δ			50	-1,072	-1,352	
Bruce et al., 1980 (4)						
Women						
Younger	1.65	57.3	26.3	2,631	2,518	
Older	1.60	66.3	70.1	2,434	2,120	
Δ				-197	-398	
Men						
Younger	1.80	72.8	26.9	4,280	4,033	
Older	1.73	76.2	70.0	3,366	3,236	
Δ				-914	-797	

Observed data are derived from previously published studies. Predicted TBK values are on basis of regression coefficients for women and men in Table 6.

vation is that women have a larger proportion of their TASM mass in their lower extremities.

As noted earlier, absolute age-related reductions in both TASM and TBK are greater in men than in women. Both components are greater in young men so that, when expressed as a relative reduction, age-related gender differences are smaller in magnitude. For example, the Reference Woman and Reference Man would have a lowering in TASM over five decades of 2.0 and 4.0 kg, respectively, a twofold gender difference in absolute muscle reduction. Expressed as a percentage, the decrease in TASM was 10.8 and 14.7% in women and men, respectively. The mechanisms leading to absolute gender differences in muscle reduction with increasing age are unknown, although the aforementioned hormonal factors are most likely involved.

Ethnicity. The present study results support and extend earlier studies that demonstrate ethnic differences in skeletal muscle mass (1, 12, 21). Moreover, our observations support a large and growing body of information related to ethnic differences in skeletal dimensions and bone mineral mass (18, 20).

Mechanisms leading to skeletal muscle differences between African-American and Caucasian subjects were not explored in the present study, and there is relatively little information available that might explain the observed differences. Kleerekoper and colleagues (18) investigated body composition and gonadal steroids in older African-American and Caucasian women. Although lean mass was larger in the African-American women, the groups had similar serum levels of androstenedione and estrone. Although serum estrone levels were related to body composition measurements in the Caucasian women, no such relationships were observed in the African-American women. Wright and colleagues (35) found no significant difference in growth hormone secretion between African-American and Caucasian premenopausal women despite ethnic differences in bone mineral density. The African-American women in this study had significantly higher serum testosterone levels (1.1 ± 0.1 nmol/l) compared with the Caucasian women (0.9 nmol/l, $P < 0.05$), a finding relevant to the observed skeletal muscle differences in

the present investigation. Perry and colleagues (24) also observed a significantly higher serum testosterone level in African-American women compared with their Caucasian counterparts. Future studies are needed to further probe the mechanisms of observed ethnic musculoskeletal differences.

Study Limitations

Sample representativeness. Our study population was limited and not randomly selected. Subjects were volunteers in good health, and they may not be representative of the general population. We restricted our recruitment to people who were ambulatory and excluded those with physical disabilities or those who participated in vigorous training programs. Last, our study included a limited number of elderly subjects, and therefore our regression models may not be indicative of appendicular skeletal muscle in very old populations. Variations in appendicular skeletal muscle mass are most likely larger in the general population than that observed in the present study. Future population studies would benefit from inclusion of DEXA appendicular skeletal muscle mass measurements because the available methods are now relatively safe and require minimal time for completion.

Age-related kinetics of muscle loss. Our regression formulas were developed on the basis of linear associations between variables in a cross-sectional cohort. There are some suggestions, however, that appendicular skeletal muscle may decrease with increasing age as a nonlinear function, through which rapid loss in bone and TBK is reported early in menopause (1, 20) and rapid TBK loss is suggested in very elderly women (2). Larger and longitudinally monitored subject populations evaluated in the future could resolve lingering issues related to the kinetics of age-related muscle loss.

Appendicular skeletal muscle and limb length measurement methods. Our investigation employed DEXA for appendicular skeletal muscle mass measurement. An earlier study of relatively young men at our center demonstrated a high correlation ($r = 0.95$, $P < 0.001$) between DEXA-measured appendicular skeletal muscle and total body skeletal muscle mass measured by computerized axial tomography (33). The ratio of appendicular skeletal muscle to total muscle mass of 0.79 ± 0.05 observed in this earlier study was similar to that of the Reference Man (~ 0.75) (31). Although these initial results support the accuracy of appendicular skeletal muscle mass measured by DEXA, a concern arises when findings from the present study are interpreted that DEXA-measured appendicular skeletal muscle includes nonmuscle fat-free components such as skin, connective tissues, and the nonlipid portion of adipose tissue. To what extent these nonmuscle components influenced our results is unknown, although their amounts are likely small relative to appendicular skeletal muscle. We are now exploring this question in a large and diverse subject population by using magnetic resonance imaging as a reference method for quantifying appendicular skeletal muscle.

Limb lengths were measured in the present study by using linear skeletal dimensions quantified by DEXA. For the upper extremity we assumed that humerus length was representative of total arm length, although there are suggestions (12, 21) that ethnic differences in appendicular dimensions are more pronounced distally. With improving software and image resolution, DEXA methods are increasingly able to provide investigators with accurate skeletal dimensions. The potential therefore exists in future studies to further explore ethnic skeletal dimension differences in vivo, particularly in bones not accessible with conventional anthropometry.

Conclusions. The present study demonstrates that, in a healthy cohort of adult subjects, four determinants (stature, weight, age, and gender) exist that explain $>80\%$ of between-individual within-ethnic group differences in skeletal muscle mass. We observed significant differences in appendicular skeletal muscle mass between African-American and Caucasian subjects. Last, we confirmed a 3-decade-old observation that TBK is reduced in older subjects and showed that our multiple-regression TBK models were similar in nature to TASM models derived on the same subjects. These TBK models gave similar TBK estimates to those observed in earlier cross-sectional and longitudinal cohorts consisting of large and diverse populations. Our appendicular skeletal muscle and TBK models are based on cross-sectional subject evaluations; a need exists to extend model development to longitudinally monitored populations. Additionally, future studies are needed to link the present findings in adults to developmental changes in skeletal muscle during childhood and adolescence.

The quantitative relationships observed between appendicular skeletal muscles and other covariates should provide the foundation for future studies that examine additional skeletal muscle determinants and interventions designed to alter skeletal muscle mass and function.

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