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Physical Activity Type and Intensity Are Associated With Abdominal Muscle Area and Density: The Multiethnic Study of Atherosclerosis

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Abstract

Background: Using data from a multiethnic cohort, the authors tested associations of multiple types and intensities of physical activity (PA) with abdominal muscle area and density.

Methods: 1895 Multiethnic Study of Atherosclerosis participants (mean age 64.6 [9.6] y) completed health history and PA questionnaires and computed tomography to quantify body composition and measurements of cardiovascular and inflammatory biomarkers. Analyses included multivariable regression.

Results: Compared with those not meeting PA guidelines for Americans, those meeting the guidelines had higher total abdominal muscle area (odds ratio, 95% confidence interval 1.60, 1.20 to 2.15), stability muscle area (1.68, 1.28 to 2.20), and stability muscle density (1.35,1.03 to 1.76). After adjustment for relevant covariates, each SD increase in total moderate to vigorous PA was associated with a higher total abdominal (β, 95% confidence interval = 0.068, 0.036 to 0.173), stability (0.063, 0.027 to 0.099), and locomotor (0.069, 0.039 to 0.099) muscle area and higher locomotor muscle density (0.065, 0.022 to 0.108, $P < .01$). Only intentional and conditioning exercise were associated with total abdominal and stability muscle density ($P < .05$). Light PA and walking were not associated with muscle area or density.

Conclusions: Most types of PA are positively associated with abdominal muscle area and density across functional categories, independent of relevant covariates. These results provide additional evidence for promoting PA for healthy muscle aging.

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Keywords

exercise; myosteatosis; sarcopenia; skeletal muscle

Skeletal muscle aging is characterized by a progressive loss of muscle mass and function that typically begins in the fourth decade of life.[1,2] Skeletal muscle aging is also characterized by an increase in fatty infiltration, which decreases muscle quality by negatively influencing strength and function, though this has been much less investigated.[3,4] This progressive loss of muscle mass, quality, and function with aging is associated with increased risk for frailty, disability, and cardiometabolic disease.[1,2] Therefore, understanding lifestyle factors that may attenuate skeletal muscle aging is of growing importance.

Regular physical activity (PA), particularly resistance training, is thought to mitigate the age-related loss of muscle mass and function. In this regard, cross-sectional and longitudinal studies of older adults have consistently shown that resistance training is associated with increases in skeletal muscle mass and density, with the latter being an indicator of fat infiltration of the muscle.[5–7] Conversely, aerobic exercise is thought to have minimal effects on increasing muscle mass, despite few studies and conflicting reports in the literature.[5,8] Indeed, the outcome of studies examining the effects of aerobic exercise varies from no change to 10% increases in muscle mass.[8] Although these studies add to our understanding of the effects of PA on muscle health, they have been limited by small sample sizes and specific exercise interventions.[5,8] Of the few cross-sectional studies that have investigated the associations between PA and muscle mass, only one reported computed tomography (CT) derived muscle outcomes,[9] and others were limited by surveys that only provided an overall PA score.[10,11]

Only 23.2% of Americans are meeting guidelines for muscle-strengthening activity.[12] PA intensity is associated with muscle quality, which is important for muscle strength (eg, mobility and power).[13,14] It was previously well accepted that loss of muscle mass during adulthood was the driver of reduced muscle strength[15,16]; however, more recent research has identified maintaining muscle density as being most critical in preventing loss in muscle strength.[17] Loss of lower body locomotor muscle density, stability, power, and total abdominal muscle density are associated with sedentary behavior, independent of PA volume and intensity.[13,18] Thus, reducing sedentary behavior and maintaining moderate to high PA volume and intensity is particularly important for older adults who experience greater declines in muscle quality, power, and strength with age.[19–21] Despite significant advances in our understanding of the physiology of muscle aging, the specific type, intensity, and volume of PA needed to maintain or increase skeletal muscle area and density are currently unknown. Given this, the aims of this study were to (1) investigate the associations between self-reported PA and abdominal muscle area and density in a large, multiethnic cohort and (2) compare muscle area and density across those who meet versus do not meet the PA guidelines for Americans.

Methods

Participants

The Multiethnic Study of Atherosclerosis (MESA) is a longitudinal study of adults from 6 regions across the United States. Details of the study design have been published previously.[22] In brief, the cohort included a total of 6814 men and women who were free from clinically apparent cardiovascular disease at the time of enrollment (July 2000 to August 2002). Participants who were enrolled in the study returned for follow-up clinic visits approximately 2, 4, 6, and 10 years after the baseline clinic visit.

At clinic visits 2 and 3 (from 2002 to 2005), a random subset of 1970 participants were enrolled in an ancillary study wherein abdominal CT scans were obtained and subsequently used to quantify the area and density of abdominal skeletal muscle. Approximately half of the 1970 participants had their scan at visit 2 and the other half at visit 3. To make the measurements contemporaneous, demographic, bio-marker, and PA data obtained during visit 2 or 3 (corresponding to when the CT scan was conducted) were used in this study. The MESA studies were approved by the institutional review board of each study site, and all participants provided written informed consent.

Abdominal Muscle Measurements

We conducted CT scans on the abdomen for body composition assessment in this study. CT combines a series of X-ray images taken from different angles to create cross-sectional images (slices) of various tissues. The abdomen was chosen to capture visceral adiposity and other measures to include muscle area and density. Abdominal muscle area and density measured by CT are strongly associated with total body muscle mass, total body muscle density, and voluntary strength.[23–25] Thus, studying abdominal muscle appears to have implications for skeletal muscle health in older adults.

Abdominal muscle, as well as visceral and subcutaneous fat, were measured from CT scans obtained at visit 2 or 3. Abdominal slices from these scans were processed using MIPAV software (version 4.1.2; National Institutes of Health) that measured fat, lean, and total tissue using a semiautomated method. Fat tissue was identified as being between −190 and −30 Hounsfield units (HU), whereas lean tissue was identified as being between 0 and 100 HU. Densities between 0 and −30 HU were labeled as undefined tissue type. Six transverse cross-sectional slices were analyzed at the following spine levels: 2 at L2/L3, 2 at L3/L4, and 2 at L4/L5.

Fat and muscle areas were calculated for the abdominal muscle groups and the subcutaneous and visceral compartments using the pixel intensities of a single slice obtained at L4/L5 and the HU criteria provided earlier. The bilateral oblique, rectus abdominis, paraspinal, and psoas muscles were defined within their unique fascial planes. These muscles were grouped into muscles of stabilization (oblique, rectus abdominis, and paraspinal muscles), muscles of locomotion (psoas muscle), and total abdominal muscle (oblique, rectus abdominis, paraspinal muscles, and psoas). For each muscle, area was determined by summing the number of pixels of 0 to 100 HU within that muscle's corresponding fascial plane. Muscle density was the average HU measurement of the pixels classified as muscle and within the muscle's distinct fascial plane. Subcutaneous adipose tissue was defined as the fat outside of the visceral cavity, not including the fat located within the muscular fascia. Visceral fat area was computed as the sum of the pixels of the appropriate HU range within the visceral cavity.

The CT imaging was interpreted by staff who were blinded to participants' clinical information. Interrater and intrarater reliability for total abdominal, subcutaneous, and visceral cavity areas was 0.99 for all measurements.[26]

Physical Activity

An interviewer-administered questionnaire, Typical Week Physical Activity Survey, was used for self-reported PA levels. This survey was adapted from the Cross-Cultural Activity Participation Study[27] and designed to identify the frequency of and time spent in various physical activities and sedentary behaviors during a typical week within the past month. The survey included 28 items in categories of household chores, yard/lawn/garden/farm care, care of children/adults, transportation, walking, dancing, sport activities (individual and team sports), conditioning activities (aerobics, cycling, jogging, rowing, swimming, and weightlifting), leisure sedentary activities (eg, watching television, reading, knitting), and occupational and volunteer activities. Where appropriate, questions differentiated between light-, moderate-, and vigorous-intensity activities with definitions of intensity and examples of activities provided. Respondents were first asked whether they participated in each category of activity. If they answered yes, they were asked questions regarding the average number of days per week and time per day engaged in these activities. Minutes of activity were summed for each discrete activity type and multiplied by the metabolic equivalent of task (MET) level.[28] Survey responses were quantified into MET minutes per week of different categories of PA based on intensity and type: light PA, total moderate to vigorous PA (MVPA; all MVPA activities), conditioning exercise (aerobics, cycling, jogging, rowing, swimming, and weightlifting), intentional exercise (walking for exercise, dancing, sport, and conditioning activities), walking, and sedentary behavior. Intentional exercise was used for determining whether participants met ($\geq$500 MET min·wk^{-1}) or did not meet ($<$500 MET min·wk^{-1}) the PA guidelines for Americans.[12]

Covariates

Standard questionnaires were used to obtain information on participant demographics, including age, sex, race/ethnicity (ie, non-Hispanic White, Chinese American, African American, Hispanic American), medical history, smoking history, and income. Smoking history was classified as never smoker (<100 cigarettes in a lifetime) or ever smoker (≥100 cigarettes in a lifetime), and income was classified as <$30,000/year and ≥$30,000/year.

Height (Accu-Hite Stadiometer, SECA) and weight (Platform Balance Scale, Detecto) were measured to the nearest 0.1 cm and 0.5 kg, respectively. Body mass index (BMI) was calculated from these variables as weight (in kilograms)/height (in meters squared). Waist circumference, waist-to-hip ratio, and blood pressure were measured using standard procedures.[22]

Venous blood was collected after a 12-hour fast, processed, and immediately stored at −80 °C. Samples were shipped to the MESA central laboratory (Laboratory for Clinical Biochemistry Research, University of Vermont) for measurement of total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, triglycerides, glucose, and inflammatory biomarker concentrations. Total and high-density lipoprotein cholesterol levels were measured using the cholesterol oxidase method (Roche Diagnostics), and triglycerides were measured using the triglyceride GB reagent (Roche Diagnostics). For triglyceride levels <400 $mg\cdot dL^{-1}$, low-density lipoprotein cholesterol was calculated using the Friedewald formula, whereas when triglycerides were >400 $mg\cdot dL^{-1}$, nuclear magnetic resonance spectroscopy was used. Glucose was measured using a Vitros analyzer (Johnson & Johnson Clinical Diagnostics). C-reactive protein, adiponectin, leptin, tumor necrosis factor-alpha, interleukin-6, and resistin concentrations were measured using Bio-Rad Luminex flow cytometry (Millipore). Average analytic coefficients of variation across several control samples ranged from 6.0% to 13.0%.

Statistical Analysis

Characteristics of the population were summarized with mean and SD or mean and SE difference for continuous variables and frequency and percentage of the study population for categorical variables. Descriptive characteristics across sex and race/ethnicity were compared by independent *t* test for continuous variables and chi-square for categorical variables. Analysis of variance was used to compare muscle area and density for those meeting versus not meeting the PA guidelines for Americans while controlling for nonmodifiable risk factors, including age, sex, and race/ethnicity.

Using multiplicative interaction terms, we tested for significant differences in the magnitude of associations between the different categories of PA and muscle area and density by age, sex, race/ethnicity, and BMI category (nonobese < 30 $kg\cdot m^{-2}$ and obese ≥ 30 $kg\cdot m^{-2}$). As there were significant and robust interactions by sex ($P < .05$), we conducted analyses stratified by sex and present data for (1) the entire cohort and (2) by sex.

Multivariable linear regression was used to determine the associations between the different categories of PA and muscle area and density while controlling for covariates. The initial model (model 1) adjusted for age, sex (for overall cohort), race/ethnicity, income, sedentary behavior, and BMI. Model 2 included model 1 plus dyslipidemia, hypertension, diabetes, and smoking. Model 3 included model 2 plus inflammatory markers (adiponectin, leptin, resistin, C-reactive protein, tumor necrosis factor-alpha, and inter-leukin-6). We included inflammatory markers in the final model as they may have direct catabolic effects on skeletal muscle[29] and have been associated with muscle area and density in the MESA cohort.[30,31] Models were also run with BMI replaced by height, visceral fat, and subcutaneous fat with no appreciable differences found. Therefore, we report models including BMI.

Multivariable logistic regression was used to determine the odds of having high muscle area or density, using the median split for each muscle group in the overall cohort and for each sex, comparing those meeting versus not meeting the PA guidelines for Americans while controlling for covariates. A score at or above the median was considered high, and a score below the median was considered low for muscle area and density. Linear and logistic regression data are presented as standardized betas (β) and odds ratios (OR) with a 95% confidence interval (CI).

Among the 1970 participants, 1902 had complete data on PA, muscle area, and muscle density. There were participants who were missing values for the covariates, resulting in an analytic sample of 1895 for comparisons across meeting versus not meeting PA guidelines for Americans and 1691 for model 3 of multivariable logistic and linear regression. In a sensitivity analysis, we examined the potential bias of missing data by running the analyses described previously with sample sizes of 1895 and 1691. All data analyses were conducted with SPSS Statistics (version 24, IBM Corp), and a P value of ≤ .05 was used to determine statistical significance.

Results

The study cohort characteristics are presented in Table 1. Overall, the mean age of participants was 64.6 years, 50% were female, and 40% were non-Hispanic White. On average, participants were overweight with a mean BMI of 28 kg·m^{-2}. Compared with men, women were older (mean [SE] difference = 0.9 [0.4] y), less likely to smoke, and had lower prevalence of dyslipidemia and diabetes but higher prevalence of hypertension and obesity ($P \leq .05$). Women also had higher levels of adiponectin, leptin, and C-reactive protein (mean [SE] difference = 7.6 [0.6] μg·mL^{-1}, 20.6 [0.9] ng·mL^{-1}, 1.6 [0.3] mg·L^{-1}, respectively, $P \leq$ .01) and reported significantly more walking and light and sedentary activity but less MVPA (mean [SE] difference = 49.6 [71.2], 1294.1 [104.7], 168.2 [50.1], and −1373.8 [216.0] MET min·wk^{-1}, respectively, $P \leq .01$). On average, men had higher levels of visceral fat and both abdominal muscle area and density than women (mean [SE] difference = 30.5 [3.1] cm^2, 36.1 [1.0] cm^2, 4.4 [0.2] HU, respectively, $P \leq .01$).

Muscle Area and Density by Meeting or Not Meeting PA Guidelines for Americans

Fewer women (54%) than men (65%) met the PA guidelines ($P \leq .01$) with African American (59%) and Hispanic (57%) participants reporting lower prevalence of meeting the guidelines than non-Hispanic White (67%) and Asian participants (63%, $P \leq .01$; Table 2). Overall, and after adjusting for age, sex, and race/ethnicity, total abdominal, stability, and locomotor muscle areas and densities were higher in participants who reported meeting the PA guidelines compared with those who did not meet the guidelines ($P \leq .01$).

Similarly, in multivariable linear regression for the full sample and with adjustment for covariates in model 3, meeting the PA guidelines was associated with a higher total abdominal, stability, and locomotor muscle area ($P \leq .01$; Table 3) and total abdominal and stability muscle density ($P \leq .05$; Table 4). In sex-stratified analysis, the associations between meeting the PA guidelines and total abdominal, stability, and locomotor muscle area, but not density, were significant in men and women ($P \leq .01$).

In multivariable logistic regression for the full sample and with adjustment for covariates in model 3, meeting the PA guidelines was associated with 60% (OR, 95% CI = 1.60, 1.20 to 2.15), 68% (OR, 95% CI = 1.68, 1.28 to 2.20), and 35% (OR, 95% CI = 1.35, 1.03 to 1.76) greater odds of high total abdominal muscle area, stability muscle area, and stability muscle density, respectively ($P \leq .05$; Table 5). In sex-stratified analysis, meeting the PA guidelines was associated with a 64% (OR, 95% CI = 1.64, 1.16 to 2.31) and 65% (OR, 95% CI = 1.65, 1.20 to 2.26) greater odds of high locomotor muscle area in men and women, respectively ($P \leq .01$).

Muscle Area and Density by Category of PA

For the full sample and with adjustment for covariates in model 1, a 1-SD increase in total MVPA was associated with higher total abdominal (β, 95% CI = 0.072, 0.041 to 0.103), stability (β, 95% CI = 0.065, 0.031 to 0.100), and locomotor (β, 95% CI = 0.076, 0.048 to 0.105) muscle area as well as a higher locomotor muscle density (β, 95% CI = 0.060, 0.017 to 0.012; $P \leq .01$ for all). These associations remained significant with the addition of covariates in models 2 and 3 (Tables 3 and 4). There were no significant associations between total MVPA and total abdominal or stability muscle density in any of the models ($P > .05$). In sex-stratified analyses, the associations between total MVPA and muscle area were significant in men and women. However, the association between total MVPA and locomotor muscle density was only significant in men ($P \leq .01$).

For the full sample and with adjustment for model 1, a 1-SD increase in intentional exercise was associated with higher levels of total abdominal (β, 95% CI = 0.074, 0.044 to 0.103), stability (β, 95% CI = 0.056, 0.023 to 0.089), and locomotor muscle area (β, 95% CI = 0.110, 0.082 to 0.137; $P \leq .001$ for all) and total abdominal (β, 95% CI = 0.050, 0.016 to 0.084), stability (β, 95% CI = 0.042, 0.008 to 0.075), and locomotor muscle density (β, 95% CI = 0.065, 0.024 to 0.106; $P \leq .05$ for all). These associations were slightly attenuated but remained significant in all models ($P \leq .05$). The associations differed by sex, with the associations between intentional exercise and muscle density significant only in men.

Similarly, and with adjustment for model 1, conditioning exercise was associated with higher levels of total abdominal (β, 95% CI = 0.068, 0.039 to 0.098), stability (β, 95% CI = 0.052, 0.019 to 0.085), and locomotor muscle area (β, 95% CI = 0.100, 0.073 to 0.127; $P \leq .01$ for all) and density (β, 95% CI = 0.055, 0.021 to 0.088; 0.046, 0.012 to 0.079; 0.071, 0.030 to 0.112, respectively, $P \leq .01$ for all). These associations were slightly attenuated but remained significant in all models ($P \leq .05$). Interestingly, these associations were stronger and more consistent in women than men.

There were no significant associations between light PA or walking with muscle area or density with the exception of a significant association between walking and locomotor muscle area in women.

There was a significant interaction of total MVPA with age for total abdominal ($P = .04$) and locomotor ($P = .02$) muscle areas whereby higher age was associated with a weaker association of MVPA with both total abdominal and locomotor muscle area (Figure 1). For Hispanic participants, and compared with non-Hispanic White participants, there was a significant interaction between total MVPA and race/ethnicity for total abdominal, stability, and locomotor muscle area but not density ($P \leq .05$; Figure 2). More specifically, and among Hispanic participants, a 1-SD increase in total MVPA was associated with a 10.8% (β, 95% CI = 0.108, 0.038 to 0.178), 9.3% (β, 95% CI = 0.093, 0.016 to 0.170), and 13.2% (β 95%

CI = 0.132, 0.068 to 0.196) higher total abdominal, stability, and locomotor muscle area, respectively, compared with 5.3% (β, 95% CI = 0.053, 0.006 to 0.100), 5.5% (β, 95% CI = 0.055, 0.002 to 0.107), and 3.7% (β, 95% CI = 0.037, −0.008 to 0.081) higher areas, respectively, in non-Hispanic White participants. There were no other significant or robust interactions between PA and race/ethnicity for muscle area or density. There were also no significant interactions between PA and BMI for muscle area or density ($P > .05$).

In a sensitivity analysis, we examined the potential impact of missing data on the associations between PA (meeting vs not meeting the PA guidelines for Americans and category of PA) and muscle area and density. Compared with the sample size of 1895, accounting for missing data by using the sample size of 1691 did not meaningfully alter the results for any of the analyses.

Discussion

In this cross-sectional analysis of a relatively large multiethnic cohort, higher levels of total MVPA were associated with higher abdominal muscle area and density with the latter only being significant for the muscles of locomotion (ie, psoas). Intentional and conditioning exercise were associated with higher abdominal muscle area and density across all muscle groups. Notably, these associations were independent of relevant covariates, including comorbidities, cardiovascular disease risk factors, and markers of inflammation. Meeting the PA guidelines for Americans, through intentional exercise, was also associated with a significantly higher total abdominal, stability, and locomotor muscle area and density compared with not meeting PA guidelines. Conversely, our data indicate that light PA and walking are not significantly associated with muscle area or density, except locomotor muscle area in women. These findings may have clinical relevance for exercise prescription in middle-age to older adults for maintaining muscle health and suggest that the intensity of exercise prescribed should include moderate to vigorous levels if the goal is to maintain muscle mass and less intramuscular fat.

There is a paucity of data examining the effects of different types and intensities of PA, as well as accumulation of PA throughout the day, on maintaining muscle area and density with age. Our findings provide evidence that different categories of MVPA are positively associated with muscle area and density and are consistent with longitudinal training studies that show significant increases in muscle area[32–34] and density[35] by CT or MRI in older adults with supervised training, including cycling, walking, or jogging. In contrast, others report no change in muscle area by CT or MRI in older adults following aerobic exercise training of similar mode and length of intervention.[8,35]

Ikenaga et al[35] reported a decrease in CT-measured low-density muscle area in the thigh following a walking and jogging interval program in older adults, whereas Goodpaster et al[6] reported that brisk walking prevented the age-associated decline in thigh muscle density but not area in older adults. In one of the only cross-sectional studies to investigate PA and CT-derived muscle density, MVPA, but not light PA, was associated with higher calf muscle density in older adults from the Health Aging Initiative (Sweden).[9] Somewhat consistent with these findings, we show that conditioning and intentional exercise (which includes walking for exercise), but not total walking or light PA, were positively associated with muscle density. Thus, additional studies in populations with wide age ranges are needed to further describe and confirm the associations between PA and various skeletal muscles.

Our results indicate that those who met the PA guidelines for Americans had greater odds of high total abdominal muscle area (60%), stability muscle area (68%), and stability muscle density (35%) compared with those who did not meet the guidelines, suggesting that this volume of exercise may be appropriate for maintaining these muscle outcomes. Furthermore, our data show positive associations between intentional and conditioning exercise with abdominal muscle area and density. These 2 categories of PA include individual and team sports as well as activities specific to improving fitness. Overall, these findings are consistent with cross-sectional evidence from masters athletes, suggesting that participating in lifelong PA, specific for sports performance and fitness, slows the age-related decline in muscle mass and function.[36,37]

There were differences between men and women in that intentional exercise was more strongly associated with muscle density in men and conditioning exercise was more strongly and consistently associated with muscle density in women. The intentional exercise category includes conditioning exercise, and it is possible that different exercise modes, frequency, or patterns (continuous vs intermittent) between men and women within the intentional exercise category contributed to the difference in findings. Furthermore, fewer women than men met the PA guidelines, with women self-reporting higher levels of light activity and walking than men, which may have also impacted the results. Future studies are needed to understand potential sex differences and the mechanisms associated with these differences.

Our data suggest that Hispanic adults may respond more favorably to high levels of MVPA on abdominal muscle area than other race/ethnic groups, but this finding needs to be con-firmed in longitudinal studies. Muscle mass and fat mass vary across race/ethnicity with a higher body fat relative to BMI in Hispanic adults when compared with other ethnicities.[38,39] There may also be race/ethnicity differences in the relative loss of muscle area and density with aging.[38] With increasing adiposity, African Americans deposit greater quantities of intermuscular fat than do non-Hispanic Whites or Asians.[40] These findings suggest that fat deposition between muscle groups may vary across race/ethnicity; however, this study did not include Hispanic participants. Using data from the National Health and Nutrition Examination Survey, Li et al[41] reported racial differences in the prevalence of presarcopenia (ie, low appendicular muscle mass) as well as temporal trends. Prevalence of presarcopenia was highest in non-Hispanic Blacks compared with non-Hispanic Whites and Mexican Americans, and prevalence significantly increased over time only among non-Hispanic Blacks. Finally, sex steroid hormones influence muscle strength, maintenance, growth, and metabolic function,[42] and levels of these hormones have been shown to vary across race/ethnicity.[43–45]

A growing body of evidence indicates that poor muscle quality, such as low muscle density, plays a critical role in impaired physical performance.[46] Indeed, muscle density is strongly related to poor muscle function,[47] impaired physical function,[48] slower gait speed,[49] and mobility limitations.[50] However, there is a growing recognition that the extent of harmful effect of low muscle density may depend on anatomical location and function and morphology of the muscle.[46,47,51] Hicks et al[52] found that, compared with thigh muscle density, average muscle density of 3 abdominal muscle groups combined (lumbar paraspinals, lateral abdominals, and rectus abdominis) was a stronger determinant of chair rise performance in 1500 non-Hispanic White and African American men and women aged 70 to 79 years. Among 1152 non-Hispanic White adults with a mean age of 66 years, lower paraspinous muscle density was associated with a slower gait speed in men and women and weaker grip strength in men only.[53] Longitudinal studies are needed to gain a better understanding of the impact of PA on muscle density decline in various skeletal muscles and their specific contributions to physical performance.

Our study has many strengths, including the use of a well-characterized, gender-balanced, middle-aged and older, ethnically diverse population with validated assessments of PA and sedentary behaviors and thorough measures of important confounders. Our study adds to the literature by including a relatively large multi-ethnic sample size of middle-aged to older men and women and including various categories of physical activities and their associations with CT-derived muscle area and density. In addition, the PA levels from this study are self-reported from free-living conditions, giving us unique information about the associations between PA and muscle health. Limitations include self-reported measures of PA and sedentary behavior. In addition, we evaluated abdominal muscle area and density, and therefore, our findings may not be applicable to peripheral muscles. The study was cross-sectional, which does not provide information on a possible causal association between PA and muscle area and density. It is possible that individuals became more inactive as a result of muscle weakness (ie, reverse causation). Given this, prospective studies are needed to determine associations between PA and change in muscle over time.

In summary, our findings indicate that total MVPA is independently associated with higher total abdominal, stability, and locomotor muscle area and locomotor muscle density, whereas intentional and conditioning exercise were associated with higher total abdominal, stability, and locomotor muscle area and density. Adults who met PA guidelines for Americans had significantly higher total abdominal muscle area and density than those who did not meet PA guidelines. Our findings also suggest that the effects of PA on muscle area and density may differ across sex and race/ethnicity and warrant future study. These results provide additional evidence for promoting PA for healthy muscle aging.

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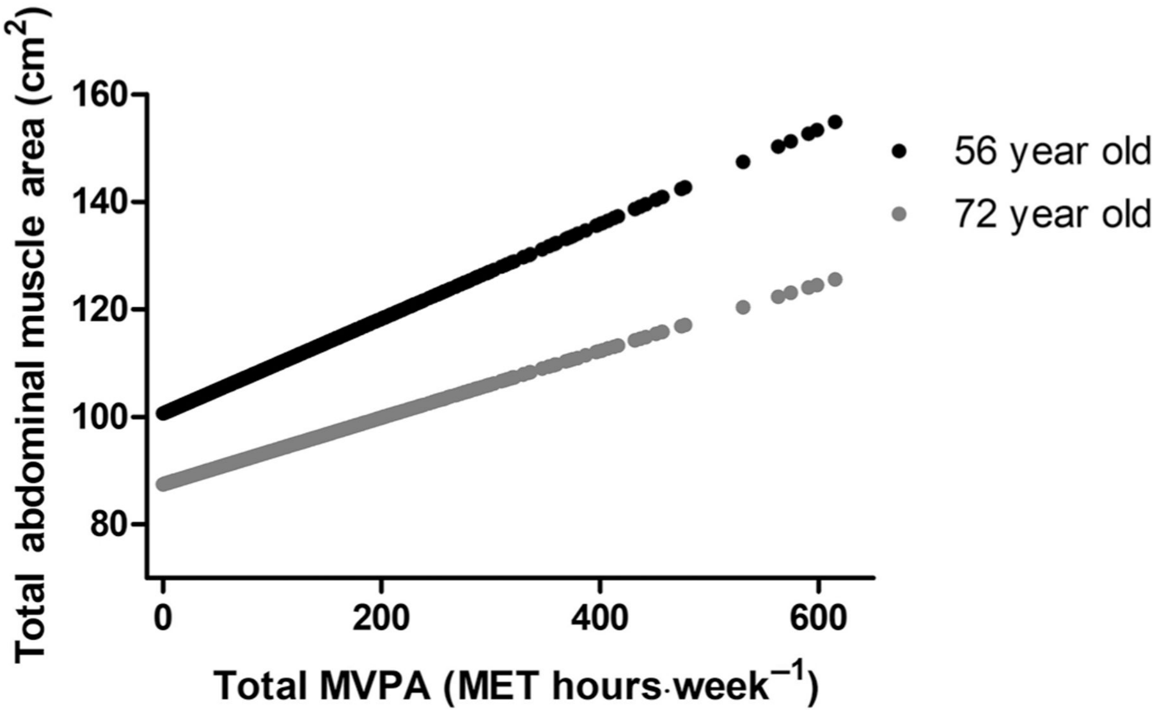

Figure 1 —.

Predicted total abdominal muscle *area* by total MVPA and age using the 25th (56 y) and 75th (72 y) percentile of age to demonstrate the significant interaction (*P* = .04). MET indicates metabolic equivalent of task; MVPA, moderate to vigorous physical activity.

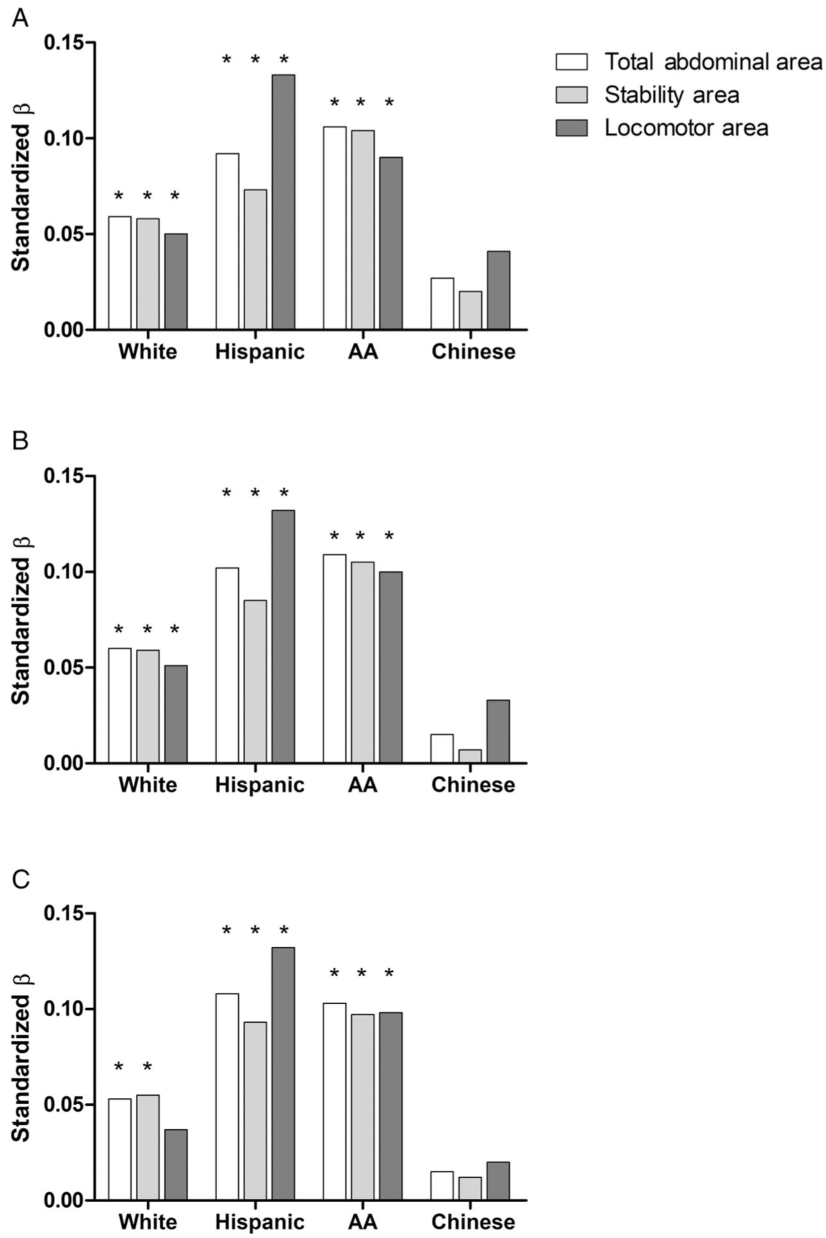

Figure 2 —.

Associations between MVPA (per 1 SD increment) and abdominal muscle *area* across race/ethnicity to demonstrate interactions. Data are presented for model 1 (A), model 2 (B), and model 3 (C); model 1 included age, race/ethnicity, income, sedentary behavior, and BMI; model 2 included model 1 plus dyslipidemia, hypertension, diabetes, and smoking; model 3 included model 2 plus adiponectin, leptin, resistin, C-reactive protein, tumor necrosis factor-alpha, and interleukin-6. AA indicates African American; BMI, body mass index; MVPA, moderate to vigorous physical activity. *$p < .05$ with a significant interaction between White and Hispanic.

Table 1

Participant Characteristics

Characteristic	Overall cohort (N = 1895)	Men (n = 944)	Women (n = 951)	*P*
Age, y	64.6 (9.6)	64.2 (9.9)	65.1 (9.4)	.04
Women, % (n)	50.2 (951)	—	—	
Ethnicity, % (n)				.04
White	40.0 (758)	41.6 (393)	38.4 (365)	
Chinese American	13.2 (251)	14.1 (133)	12.4 (118)	
African American	20.9 (397)	18.2 (172)	23.7 (225)	
Hispanic	25.8 (489)	26.1 (246)	25.6 (243)	
Ever smoker, % (n)	54.0 (1023)	64.8 (612)	43.2 (411)	<.01
Dyslipidemia, % (n)	38.4 (728)	43.3 (409)	33.5 (319)	<.01
Diabetes, % (n)	14.2 (270)	16.1 (152)	12.4 (118)	.03
Hypertension, % (n)	46.7 (885)	43.1 (407)	50.3 (478)	<.01
Obese, % (n)	29.9 (567)	26.0 (245)	33.9 (322)	<.01
Body composition				
BMI, kg·m^{-2}	28.0 (5.1)	27.7 (4.3)	28.4 (5.8)	<.01
Waist circumference, cm	97.9 (13.9)	98.6 (11.7)	97.2 (15.8)	.03
Waist to hip ratio	0.9 (0.1)	1.0 (0.1)	0.9 (0.1)	<.01
Subcutaneous fat area, cm^2	253.8 (117.8)	211.3 (95.0)	296.9 (123.0)	<.01
Visceral fat area, cm^2	146.4 (68.1)	161.7 (71.4)	131.2 (61.0)	<.01
Abdominal muscle area, cm^2	98.3 (27.5)	116.4 (23.9)	80.4 (17.4)	<.01
Stability muscle area, cm^2	74.6 (21.8)	87.3 (20.1)	62.1 (15.1)	<.01
Locomotor muscle area, cm^2	23.7 (7.4)	29.1 (6.1)	18.3 (3.8)	<.01
Abdominal muscle density, HU	42.2 (5.5)	44.4 (4.9)	40.1 (5.2)	<.01
Stability muscle density, HU	39.5 (6.1)	42.1 (5.4)	37.0 (5.7)	<.01
Locomotor muscle density, HU	50.3 (5.2)	51.2 (4.9)	49.3 (5.3)	<.01
Activity levels				
Sedentary, MET min·wk^{-1}	1678.9 (1094.0)	1594.5 (1030.4)	1762.7 (1148.1)	<.01
Light, MET min·wk^{-1}	3303.2 (2368.8)	2653.7 (2000.4)	3947.9 (2525.8)	<.01
MVPA, MET min·wk^{-1}	4945.2 (4749.5)	5634.7 (5337.1)	4260.9 (3969)	<.01

Characteristic	Overall cohort (N = 1895)	Men (n = 944)	Women (n = 951)	*P*
Intentional, MET min·wk^{-1}	1387.5 (1821.9)	1547.6 (2020.1)	1228.5 (1586.3)	<.01
Conditioning, MET min·wk^{-1}	451.5 (1028.1)	539.2 (1228.7)	364.4 (770.4)	<.01
Walking, MET min·wk^{-1}	1313.9 (1549.5)	1289.0 (1445.0)	1338.6 (1647.2)	<.01
Inflammatory markers				
Adiponectin, μg·mL^{-1}	20.8 (13.3)	17.0 (10.8)	24.6 (14.4)	<.01
Leptin, ng·mL^{-1}	20.6 (22.0)	10.2 (10.6)	30.8 (25.3)	<.01
Resistin, ng·mL^{-1}	16.4 (8.5)	16.2 (9.5)	16.5 (7.3)	.46
Interleukin-6, pg·mL^{-1}	2.4 (1.8)	2.3 (1.8)	2.4 (1.8)	.09
C-reactive protein, mg·L^{-1}	3.2 (7.1)	2.4 (4.5)	4.0 (8.8)	<.01
TNF-α, pg·mL^{-1}	5.7 (9.6)	5.8 (10.1)	5.7 (9.2)	.93

Abbreviations: BMI, body mass index; HU, Hounsfield units; MET, metabolic equivalents of task; MVPA, moderate to vigorous physical activity; n, sample size; TNF-α, tumor necrosis factor-alpha. Note: *P* value represents significance between men and women; data are presented as mean (SD) unless otherwise stated.

Table 2

Comparison of Abdominal Muscle Area and Density Across Those Meeting (Yes) Versus Not Meeting (No) the Physical Activity Guidelines for Americans

	Overall cohort			Men			Women		
Characteristic	**No (n = 718)**	**Yes (n = 1177)**	***P***	**No (n = 325)**	**Yes (n = 619)**	***P***	**No (n = 393)**	**Yes (n = 558)**	***P***
Muscle area, cm^2									
Total abdominal muscle	96.1 (0.7)	99.7 (0.5)	<.01	113.4 (1.1)	118.0 (0.8)	<.01	78.8 (0.7)	81.5 (0.6)	<.01
Stability muscle	73.1 (0.6)	75.6 (0.5)	<.01	85.2 (1.0)	88.4 (0.7)	.01	61.0 (0.7)	62.9 (0.6)	.03
Locomotor muscle	23.0 (0.2)	24.1 (0.1)	<.01	28.2 (0.3)	29.6 (0.5)	<.01	17.8 (0.2)	18.7 (0.1)	<.01
Muscle density, HU									
Total abdominal muscle	41.8 (0.2)	42.5 (.01)	<.01	44.0 (0.2)	44.6 (0.2)	.04	39.6 (0.2)	40.4 (0.2)	<.01
Stability muscle	39.1 (0.2)	39.8 (0.1)	<.01	41.8 (0.3)	42.4 (0.2)	.05	36.5 (0.2)	37.3 (0.2)	.01
Locomotor muscle	49.8 (0.2)	50.6 (0.1)	<.01	50.9 (0.3)	51.4 (0.2)	.08	48.8 (0.3)	49.7 (0.2)	<.01

Abbreviation: HU, Hounsfield units. Note: Data are presented as marginal mean (SE). Covariates include sex (for overall cohort), age, and race/ethnicity.

Table 3

Associations Between Physical Activity (per 1 SD Increment) and Abdominal Muscle Area (Model 3; N = 1691)

Muscle area	Overall cohort β (95% CI)	Men β (95% CI)	Women β (95% CI)
Meeting PAGA			
Total abdominal	0.081 (0.043 to 0.119)	0.085 (0.030 to 0.141)	0.097 (0.038 to 0.155)
Stability	0.077 (0.03 to 0.116)	0.074 (0.016 to 0.133)	0.084 (0.025 to 0.143)
Locomotor	0.076 (0.037 to 0.114)	0.088 (0.032 to 0.145)	0.106 (0.045 to 0.168)
MVPA			
Total abdominal	0.068 (0.036 to 0.173)	0.082 (0.023 to 0.141)	0.093 (0.034 to 0.151)
Stability	0.063 (0.027 to 0.099)	0.071 (0.009 to 0.133)	0.086 (0.026 to 0.145)
Locomotor	0.069 (0.039 to 0.099)	0.087 (0.028 to 0.148)	0.084 (0.021 to 0.147)
Intentional exercise			
Total abdominal	0.068 (0.038 to 0.099)	0.099 (0.043 to 0.154)	0.090 (0.031 to 0.148)
Stability	0.052 (0.018 to 0.086)	0.067 (0.009 to 0.126)	0.071 (0.011 to 0.130)
Locomotor	0.101 (0.073 to 0.129)	0.164 (0.108 to 0.220)	0.130 (0.069 to 0.192)
Conditioning exercise			
Total abdominal	0.063 (0.032 to 0.093)	0.097 (0.042 to 0.153)	0.079 (0.022 to 0.137)
Stability	0.049 (0.015 to 0.083)	0.069 (0.011 to 0.127)	0.069 (0.010 to 0.128)
Locomotor	0.090 (0.061 to 0.118)	0.153 (0.097 to 0.209)	0.090 (0.028 to 0.151)
Light physical activity			
Total abdominal	0.007 (−0.025 to 0.040)	0.013 (−0.045 to 0.071)	0.014 (−0.045 to 0.073)
Stability	0.005 (−0.031 to 0.041)	0.010 (−0.050 to 0.071)	0.014 (−0.046 to 0.073)
Locomotor	0.012 (−0.018 to 0.042)	0.018 (−0.041 to 0.076)	0.009 (−0.053 to 0.072)
Walking			
Total abdominal	0.018 (−0.013 to 0.050)	0.007 (−0.049 to 0.064)	0.055 (−0.004 to 0.144)
Stability	0.017 (−0.017 to 0.052)	0.007 (−0.052 to 0.065)	0.045 (−0.014 to 0.105)
Locomotor	0.019 (−0.001 to 0.005)	0.007 (−0.050 to 0.064)	0.071 (0.009 to 0.134)

Abbreviations: β, standardized beta; CI, confidence interval; MVPA, moderate to vigorous physical activity; PAGA, Physical Activity Guidelines for Americans. Note: Model 3 included age, sex (for overall cohort), race/ethnicity, income, sedentary behavior, BMI, dyslipidemia, hypertension, diabetes, smoking, adiponectin, leptin, resistin, C-reactive protein, tumor necrosis factor-alpha, and interleukin-6.

Table 4

Multivariable Linear Regression for the Associations of Physical Activity (per 1 SD Increment) and Abdominal Muscle Density (Model 3; N = 1691)

Muscle density	Overall β (95% CI)	Men β (95% CI)	Women β (95% CI)
Meeting PAGA			
Total abdominal density	0.041 (0.005 to 0.077)	0.029 (−0.024 to 0.082)	0.031 (−0.021 to 0.084)
Stability density	0.039 (0.003 to 0.076)	0.030 (−0.023 to 0.083)	0.026 (−0.027 to 0.079)
Locomotor density	0.033 (−0.009 to 0.075)	0.019 (−0.042 to 0.080)	0.038 (−0.022 to 0.097)
MVPA			
Total abdominal density	0.032 (−0.003 to 0.067)	0.049 (−0.007 to 0.105)	0.028 (−0.025 to 0.082)
Stability density	0.020 (−0.015 to 0.546)	0.032 (−0.024 to 0.089)	0.019 (−0.034 to 0.072)
Locomotor density	0.065 (0.022 to 0.108)	0.091 (0.027 to 0.155)	0.048 (−0.012 to 0.109)
Intentional exercise			
Total abdominal density	0.045 (0.011 to 0.079)	0.069 (0.016 to 0.122)	0.026 (−0.027 to 0.078)
Stability density	0.037 (0.004 to 0.070)	0.059 (0.007 to 0.112)	0.020 (−0.033 to 0.073)
Locomotor density	0.060 (0.018 to 0.102)	0.083 (0.022 to 0.143)	0.036 (−0.024 to 0.096)
Conditioning exercise			
Total abdominal density	0.044 (0.010 to 0.078)	0.048 (−0.005 to 0.101)	0.067 (0.015 to 0.119)
Stability density	0.035 (0.002 to 0.069)	0.035 (−0.018 to 0.088)	0.063 (0.010 to 0.115)
Locomotor density	0.062 (0.021 to 0.104)	0.076 (0.016 to 0.137)	0.060 (0.001 to 0.119)
Light physical activity			
Total abdominal density	0.017 (−0.019 to 0.053)	0.049 (−0.006 to 0.104)	−0.004 (−0.054 to 0.046)
Stability density	0.009 (−0.026 to 0.045)	0.044 (−0.011 to 0.099)	−0.014 (−0.067 to 0.039)
Locomotor density	0.039 (−0.005 to 0.082)	0.051 (−0.012 to 0.114)	0.029 (−0.031 to 0.089)
Walking			
Total abdominal density	−0.008 (−0.042 to 0.026)	−0.029 (−0.082 to 0.024)	0.001 (−0.056 to 0.058)
Stability density	−0.013 (−0.047 to 0.020)	−0.036 (−0.090 to 0.017)	−0.004 (−0.057 to 0.048)
Locomotor density	0.013 (−0.029 to 0.055)	0.002 (−0.062 to 0.067)	0.018 (−0.041 to 0.078)

Abbreviations: β, standardized beta; CI, confidence interval; MVPA, moderate to vigorous physical activity; PAGA, Physical Activity Guidelines for Americans. Note: Model 3 included age, sex (for overall cohort), race/ethnicity, income, sedentary behavior, BMI, dyslipidemia, hypertension, diabetes, smoking, adiponectin, leptin, resistin, C-reactive protein, tumor necrosis factor-alpha, and interleukin-6.

Table 5

Multivariable Logistic Regression for the Associations Between Abdominal Muscle Area and Density Across Those Meeting Versus Not Meeting the Physical Activity Guidelines for Americans (Model 3; N = 1691)

	Overall cohort OR (95% CI)	Men OR (95% CI)	Women OR (95% CI)
Muscle area, cm^2			
Total abdominal muscle	1.603 (1.197 to 2.146)	1.245 (0.890 to 1.743)	1.256 (0.910 to 1.734)
Stability muscle	1.678 (1.283 to 2.195)	1.309 (0.945 to 1.814)	1.305 (0.950 to 1.794)
Locomotor muscle	1.284 (0.924 to 1.783)	1.637 (1.161 to 2.306)	1.647 (1.199 to 2.262)
Muscle density, HU			
Total abdominal muscle	1.280 (0.987 to 1.660)	0.952 (0.675 to 1.342)	1.082 (0.764 to 1.532)
Stability muscle	1.347 (1.032 to 1.757)	0.920 (0.649 to 1.304)	1.183 (0.835 to 1.674)
Locomotor muscle	0.962 (0.769 to 1.205)	0.944 (0.685 to 1.301)	0.967 (0.702 to 1.334)

Abbreviations: CI, confidence interval; HU, Hounsfield units; OR, odds ratio. Note: Model 3 included age, sex (for overall cohort), race/ethnicity, income, sedentary behavior, BMI, dyslipidemia, hypertension, diabetes, smoking, adiponectin, leptin, resistin, C-reactive protein, tumor necrosis factor-alpha, and interleukin-6. Median cutpoints for high muscle area and density for overall cohort: total abdominal muscle area (≥94.67 cm^2), stability muscle area (≥72.13 cm^2), locomotor muscle area (≥22.56 cm^2), total abdominal muscle density (≥42.70 HU), stability muscle density (≥39.87 HU), and locomotor muscle density (≥50.89 HU); men: total abdominal muscle area (≥115.20 cm^2), stability muscle area (≥86.51 cm^2), locomotor muscle area (≥28.80 cm^2), total abdominal muscle density (≥45.04 HU), stability muscle density (≥42.67 HU), and locomotor muscle density (≥51.91 HU); women: total abdominal muscle area (≥79.14 cm^2), stability muscle area (≥60.53 cm^2), locomotor muscle area (≥18.06 cm^2), total abdominal muscle density (≥40.35 HU), stability muscle density (≥37.16 HU), and locomotor muscle density (≥50.06 HU).