Associations of BMI and adipose tissue area and density with incident mobility limitation and poor performance in older adults[1–3]

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ABSTRACT

Background: Obesity is a risk factor for disability, but risk of specific adipose depots is not completely understood.

Objective: We investigated associations between mobility limitation, performance, and the following adipose measures: body mass index (BMI) and areas and densities of visceral adipose tissue (VAT), subcutaneous adipose tissue (SAT), and intermuscular adipose tissue (IMAT) in older adults.

Design: This was a prospective population-based study of men (*n* = 1459) and women (*n* = 1552) initially aged 70–79 y and free from mobility limitation. BMI was determined from measured height and weight. Adipose tissue area and density in Hounsfield units were measured in the thigh and abdomen by using computed tomography. Mobility limitation was defined as 2 consecutive reports of difficulty walking one-quarter mile or climbing 10 steps during semiannual assessments over 13 y. Poor performance was defined as a gait speed <1 m/s after 9 y of follow-up (*n* = 1542).

Results: In models adjusted for disability risk factors, BMI, and areas of VAT, abdominal SAT, and IMAT were positively associated with mobility limitation in men and women. In women, thigh SAT area was positively associated with mobility limitation risk, whereas VAT density was inversely associated. Associations were similar for poor performance. BMI and thigh IMAT area (independent of BMI) were particularly strong indicators of incident mobility limitation and poor performance. For example, in women, the HR (95% CI) and OR (95% CI) associated with an SD increment in BMI for mobility limitation and poor performance were 1.31 (1.21, 1.42) and 1.41 (1.13, 1.76), respectively. In men, the HR (95% CI) and OR (95% CI) associated with an SD increment in thigh IMAT for mobility limitation and poor performance were 1.37 (1.27, 1.47) and 1.54 (1.18, 2.02), respectively.

Conclusions: Even into old age, higher BMI is associated with mobility limitation and poor performance. The amount of adipose tissue in abdominal and thigh depots may also convey risk beyond BMI. *Am J Clin Nutr* 2014;99:1059–65.

INTRODUCTION

Disability rates have achieved modest declines in the elderly US population (1). However, steady increases in obesity in older adults (2) may mitigate these improvements (3–5). Studies from recent years have provided convincing evidence that links obesity and disability (6–9), including 30–150% greater risk of incident disability relative to normal weight (8, 9). Similarly,

a systematic review concluded that obesity is consistently and positively associated with disability in older adults (10).

Most studies have classified individuals as obese by using BMI, which is an indicator of overall adiposity. Additional adiposity measures may provide insight into disability relationships. For example, studies have reported that abdominal adipose tissue estimated from waist circumference is a better predictor of disability than BMI (11, 12). However, little is known regarding specific adipose depots (ie, measured with radiographic imaging) or other characteristics of adipose tissue such as adipose tissue density.

Previously, we identified adipose density measured from the Hounsfield units (HU)[4] of computed tomography images as a novel marker of mortality risk in older adults (13). Denser adipose tissue was associated with increased mortality risk independent of adipose tissue area and BMI. We propose that adipose tissue density may provide insight into relations between adiposity and disability indicators.

The aims of this study were to provide a comprehensive assessment of adiposity and risk of mobility limitation and poor

performance in older adults. Specifically, we explored associations with BMI and areas and densities of adipose depots in the abdomen [visceral adipose tissue (VAT) and subcutaneous adipose tissue (SAT)] and thigh [SAT and intermuscular adipose tissue (IMAT)].

SUBJECTS AND METHODS

Subjects

We used data from the Health, Aging, and Body Composition Study (Health ABC). Health ABC is a prospective, longitudinal study of 3075 community-dwelling black and white men and women aged 70–79 y. Participants were recruited from a random sample of white Medicare beneficiaries and all black Medicare-eligible residents in the Memphis, TN, and Pittsburgh, PA, areas. All participants were initially free of mobility limitation defined as no difficulty walking one-quarter mile or climbing 10 steps and free of difficulty performing basic activities of daily living. Exclusion criteria were active cancer treatment in the previous 3 y, participation in a lifestyle intervention, or planned move from the study area within 3 y. Baseline data from interviews and a clinic-based examination were collected between April 1997 and June 1998.

Adiposity measures

BMI was calculated from height measured with a stadiometer and weight measured with a calibrated scale. Computed tomography imaging of the abdomen at the L4/L5 vertebrae and midthigh was performed in Memphis [Somatom Plus 4 scanner (Siemens) or PQ 200S (Picker)] and Pittsburgh (9800 Advantage; General Electric). Tissue areas (cm^2) were calculated by multiplying the number of pixels of a given tissue by the pixel area by using Interactive Data Language software (RSI Systems). Tissue types were identified on the basis of radiographic density (HU), which was calibrated to distilled water (0 HU) and air (−1000 HU). Thus, higher HU indicated more-dense tissue. Adipose tissue areas were defined as voxels between −150 and −30 HU. After distinguishing fat from lean and bone tissues, VAT was distinguished from SAT by tracing along the fascial plane defining the internal abdominal wall. Adipose tissue density was assessed from the mean HU. Adipose measures were missing or outside of the image-viewing field for $n = 114$ (VAT area), $n = 191$ (abdominal SAT area), $n = 64$ (thigh SAT area, IMAT area, thigh SAT density, and IMAT density), $n = 119$ (VAT density), and $n = 209$ (abdominal SAT density), which resulted in differing numbers of participants by measure.

Outcomes

Self-reported physical function was assessed during annual clinic visits and telephone interviews every 6 mo over 13 y of follow-up. Mobility limitation was defined as 2 consecutive reports of having difficulty walking one-quarter mile or climbing 10 steps. Reports must have involved the same function (ie, 2 reports of difficulty walking one-quarter mile or 2 reports of difficulty climbing stairs). If participants missed a study visit, target dates for when the visit should have been completed were used to calculate the time to event or censorship. When questions were not answered, missing data were imputed by interpolating between the most-recent previous visit with data and the first following visit with data. A final determination of limitation status was made from an interview or, if needed, a proxy interview and hospital records.

Gait speed was examined as an objective measure of performance. Usual gait speed over 6 m was assessed 9 y after the baseline study visit in $n = 1542$. Participants were instructed to walk at their normal pace for the duration of the test. Timing was started with the first footfall and stopped with the first footfall after crossing the end line. Gait speed <1.0 m/s was used to identify poor performance (14, 15).

Covariates

Baseline covariates related to adiposity or mobility limitation were chosen a priori including age, education, race, study site, smoking status, prevalent diabetes, cancer, coronary heart disease from self-report and medications (coronary bypass, angioplasty, myocardial infarction, or angina), pulmonary disease (asthma, chronic bronchitis, emphysema, or chronic obstructive pulmonary disease), physical activity, self-reported midlife weight, and knee pain. Education was categorized as less than high school, high school, or postsecondary education. Smoking was categorized as never, former, or current. Prevalent disease was determined from self-report, medications, and clinical assessments. Physical activity was assessed as the activity spent walking or exercising in the 7 d before baseline (16). Pain was determined from self-reported presence or absence of pain in either knee.

Statistical analysis

Differences between groups were compared by using 2-sided t tests or chi-square tests. Correlations between BMI and adipose area and density were examined by using Spearman's correlation coefficient (r). Sequentially adjusted Cox proportional hazards models were used to estimate HRs and 95% CIs for risk of mobility limitation. HRs were expressed per sex- and race-specific SDs of BMI and adipose area and density. Models were stratified by sex because of known differences in body composition and physical performance (6, 17). The proportional hazards assumption was tested by using Schoenfeld residuals and was not met for physical activity, which was modeled as time varying. Model 1 was adjusted for age, race, and study site. Model 2 was additionally adjusted for education, smoking status, prevalent disease, physical activity, midlife weight, and pain. Model 3 was further adjusted for BMI to determine whether adipose measures were associated with mobility limitation beyond risk attributable to BMI. Collinearity assessment within models revealed mean variance inflation factors <1.7. Sensitivity analyses were conducted with the exclusion of participants with BMI (in kg/m^2) <20 because of possible relationships between underweight and limitation (18).

Logistic regression was used to estimate ORs and 95% CIs for poor performance per SD increment in adipose measures. Models were sequentially adjusted for the same risk factors as in Cox models. All analyses were performed with STATA software (version 12.1; StataCorp LP). Significance was determined at $P < 0.05$.

RESULTS

The mean (±SD) age of the analytic sample at baseline was 74.2 ± 2.87 y, 51.5% of subjects were women, and 41.5% of

subjects were black. Baseline characteristics for participants (n = 3011) with measures of thigh adipose tissue are presented in **Table 1**. Participants who developed mobility limitation were predominately women, older, black, less educated, and more likely to report current or former smoking in addition to being heavier, more obese, and having more comorbid conditions. BMI was positively associated with all adipose areas and inversely correlated with all measures of adipose density (P < 0.001; **Table 2**). The mean follow-up for mobility limitation was ~6 y. During follow-up, 2243 participants (129 participants/1000 person-years) developed mobility limitation.

Relationships between adipose measures and risk of mobility limitation are shown in **Table 3**. In minimally adjusted models (model 1), BMI and all adipose depot areas were positively associated with risk of mobility limitation in men and women. Associations remained significant with adjustment for covariates in model 2 except for thigh SAT area in men. With additional adjustment for BMI (model 3), the following adipose depots remained associated with risk: VAT area in men (HR: 1.10; 95% CI 1.01, 1.19), IMAT area in men and women [HRs: 1.37 (95% CI 1.27, 1.47) and 1.08 (95% CI 1.00, 1.16), respectively], abdominal SAT area (HR: 1.13; 95% CI 1.02, 1.26), and thigh SAT

area (HR: 1.18; 95% CI 1.08, 1.28) in women. In model 1 (Table 3), VAT and IMAT density were inversely associated with risk of mobility limitation in men and women. With adjustment for covariates (model 2), thigh IMAT density remained marginally associated with risk in men, whereas VAT and IMAT density remained associated in women. After adjustment for BMI (model 3), abdominal SAT density became positively associated with mobility limitation (HR: 1.10; 95% CI 1.02, 1.18) in men, whereas all relations were attenuated in women. The exclusion of participants with BMI <20 did not appreciably change relations for any adipose measure (not shown).

BMI and areas of VAT, abdominal SAT, thigh SAT, and thigh IMAT were all associated with increased odds of having poor performance in model 1 (**Table 4**) in men and women. Associations for VAT area were attenuated for men and women with additional adjustment for covariates (model 2). Thigh SAT area in men was marginally associated with poor performance in model 3 (OR: 1.22; 95% CI: 1.00, 1.50), whereas thigh IMAT area was associated in men and women [ORs: 1.54 (95% CI: 1.18, 2.02) and 1.25 (95% CI 1.01, 1.54), respectively]. IMAT density in men and VAT density in women were associated with poor performance in model 1 (Table 4). With adjustment for

TABLE 1
Characteristics at baseline of participants in the Health ABC with thigh adipose tissue measures (n = 3011) according to final mobility-limitation classification[1]

	No mobility limitation	Mobility limitation	P
Women [n (%)]	381 (45.9)	1171 (53.7)	<0.001
Age (y)	73.8 ± 2.85[2]	74.3 ± 2.87	<0.001
Black race [n (%)]	290 (34.9)	959 (44.0)	<0.001
Pittsburgh site [n (%)]	443 (53.3)	1056 (48.4)	<0.001
Less than high school graduate [n (%)]	154 (18.6)	599 (27.5)	<0.001
High school graduate [n (%)]	257 (31.1)	727 (33.4)	—
Postsecondary [n (%)]	416 (50.3)	850 (39.1)	—
Never smoker [n (%)]	397 (48.0)	929 (42.7)	0.01
Current smoker [n (%)]	70 (8.45)	239 (11.0)	—
Former smoker [n (%)]	361 (43.6)	1010 (46.4)	—
Cancer [n (%)]	122 (14.8)	399 (18.4)	0.02
Diabetes [n (%)]	78 (9.39)	376 (17.3)	<0.001
Hypertension [n (%)]	286 (34.4)	877 (40.2)	0.003
Coronary heart disease [n (%)]	118 (14.4)	429 (20.1)	0.001
Physical activity (kcal · kg^{-1} · wk^{-1})	1394 ± 2205	919.4 ± 1760	<0.001
Midlife weight (kg)	70.0 ± 12.9	72.4 ± 14.0	<0.001
Weight (kg)	72.7 ± 13.6	76.8 ± 15.1	<0.001
BMI (kg/m^2)	26.0 ± 3.89	27.9 ± 4.93	<0.001
<20.0 kg/m^2 [n (%)]	39 (4.69)	81 (3.72)	<0.001
20.0 to <25.0 kg/m^2 [n (%)]	307 (36.9)	544 (25.0)	—
25.0–29.9 kg/m^2 [n (%)]	366 (44.0)	916 (42.0)	—
≥30.0 kg/m^2 [n (%)]	119 (14.3)	639 (29.3)	—
VAT area (cm^2)	131 ± 60.9	148 ± 68.8	<0.001
Abdominal SAT area (cm^2)	255 ± 103	296 ± 125	<0.001
Thigh SAT area (cm^2)	134 ± 71.0	165 ± 98.6	<0.001
Thigh IMAT area (cm^2)	17.0 ± 9.75	22.0 ± 13.6	<0.001
VAT density (HU)	−85.7 ± 10.2	−87.2 ± 9.67	<0.001
Abdominal SAT density (HU)	−96.3 ± 9.48	−97.1 ± 8.95	0.04
Thigh SAT density (HU)	−105 ± 11.6	−106 ± 11.2	0.003
Thigh IMAT density (HU)	−71.8 ± 11.0	−74.3 ± 10.3	<0.001

[1] Differences between groups were tested by using 2-sided t tests for continuous variables or chi-square tests for categorical variables. Coronary heart disease was determined as any of the following: coronary bypass, angioplasty, myocardial infarction, or angina. Health ABC, Health, Aging, and Body Composition Study; HU, Hounsfield units; IMAT, intermuscular adipose tissue; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue.

[2] Mean ± SD (all such values).

TABLE 2
Spearman correlations (*r*) of BMI and adipose measures in Health ABC participants[1]

	BMI	VAT area	Abdominal SAT area	Thigh SAT area	Thigh IMAT area	VAT density	Abdominal SAT density	Thigh SAT density	Thigh IMAT density
BMI	1.00								
VAT area	0.58	1.00							
Abdominal SAT area	0.75	0.35	1.00						
Thigh SAT area	0.51	0.07	0.79	1.00					
Thigh IMAT area	0.66	0.48	0.58	0.38	1.00				
VAT density	−0.46	−0.63	−0.42	−0.21	−0.35	1.00			
Abdominal SAT density	−0.31	−0.11	−0.63	−0.56	−0.22	0.60	1.00		
Thigh SAT density	−0.19	−0.03	−0.38	−0.52	−0.19	0.17	0.47	1.00	
Thigh IMAT density	−0.35	−0.18	−0.57	−0.58	−0.54	0.37	0.58	0.82	1.00

[1] Data are for all participants with nonmissing data for each measure of adiposity (*n* = 2855). *P* < 0.001 for all correlations except the VAT area and thigh SAT density (*P* = 0.13). Health ABC, Health, Aging, and Body Composition Study; IMAT, intermuscular adipose tissue; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue.

additional covariates (model 2), only IMAT density in men persisted and remained associated with poor performance even with adjustment for BMI (OR: 0.80; 95% CI: 0.67, 0.97; model 3).

DISCUSSION

To the best of our knowledge, these findings provide new insight into associations between obesity, mobility limitation, and poor performance by exploring multiple radiographic measures of adipose tissue including adipose density, which is a novel

indicator of adipose tissue characteristics. Our results suggest that BMI as well as adipose depot area are robustly associated with risk of mobility limitation and poor performance. In addition, adipose area may convey risk beyond BMI for select depots. For every SD increment in VAT and thigh IMAT area, there was 10% and 37%, respectively, increased risk of mobility limitation in men. In women, for every SD increment in abdominal SAT, thigh SAT, and thigh IMAT area, there was 13%, 18%, and 8%, respectively, increased risk of mobility limitation. Adipose tissue density may also convey risk of incident mobility limitation and

TABLE 3
Associations between BMI and adipose measures at baseline and risk of mobility limitation over 13-y follow-up in Health ABC participants stratified by sex[1]

	No. at risk	No. of events	Event rate per 1000 person-years	Model 1	P	Model 2	P	Model 3	P
Men									
BMI	1491	1031	108	1.25 (1.17, 1.33)[2]	<0.001	1.18 (1.09, 1.27)	<0.001	—	—
VAT area	1434	989	106	1.24 (1.17, 1.32)	<0.001	1.14 (1.06, 1.21)	<0.001	1.10 (1.01, 1.19)	0.02
Abdominal SAT area	1405	970	106	1.18 (1.11, 1.26)	<0.001	1.09 (1.01, 1.18)	0.03	1.01 (0.91, 1.12)	0.81
Thigh SAT area	1459	1009	107	1.11 (1.05, 1.19)	0.001	1.05 (0.98, 1.13)	0.14	0.97 (0.89, 1.06)	0.53
Thigh IMAT area	1459	1009	107	1.39 (1.31, 1.47)	<0.001	1.36 (1.27, 1.46)	<0.001	1.37 (1.27, 1.47)	<0.001
VAT density	1431	988	106	0.92 (0.85, 0.98)	0.02	0.99 (0.92, 1.06)	0.76	1.04 (0.96, 1.13)	0.35
Abdominal SAT density	1395	962	106	1.00 (0.94, 1.07)	0.90	1.06 (0.98, 1.13)	0.13	1.10 (1.02, 1.18)	0.01
Thigh SAT density	1459	1009	107	1.02 (0.95, 1.08)	0.62	1.03 (0.96, 1.11)	0.36	1.06 (0.99, 1.13)	0.13
Thigh IMAT density	1459	1009	107	0.89 (0.84, 0.95)	0.001	0.93 (0.87, 1.00)	0.05	0.97 (0.90, 1.04)	0.35
Women									
BMI	1584	1199	136	1.46 (1.37, 1.55)	<0.001	1.31 (1.21, 1.42)	<0.001	—	—
VAT area	1527	1152	135	1.27 (1.20, 1.35)	<0.001	1.10 (1.03, 1.17)	0.004	1.02 (0.94, 1.09)	0.70
Abdominal SAT area	1479	1114	134	1.33 (1.25, 1.41)	<0.001	1.22 (1.13, 1.31)	<0.001	1.13 (1.02, 1.26)	0.02
Thigh SAT area	1552	1171	135	1.34 (1.26, 1.42)	<0.001	1.25 (1.16, 1.34)	<0.001	1.18 (1.08, 1.28)	<0.001
Thigh IMAT area	1552	1171	135	1.27 (1.21, 1.34)	<0.001	1.14 (1.07, 1.22)	<0.001	1.08 (1.00, 1.16)	0.04
VAT density	1525	1151	135	0.84 (0.78, 0.89)	<0.001	0.91 (0.84, 0.97)	0.007	0.98 (0.90, 1.05)	0.52
Abdominal SAT density	1471	1107	134	0.97 (0.91, 1.03)	0.26	0.95 (0.89, 1.02)	0.17	1.00 (0.93, 1.07)	0.95
Thigh SAT density	1552	1171	135	0.97 (0.92, 1.03)	0.36	0.96 (0.90, 1.02)	0.15	0.97 (0.91, 1.03)	0.26
Thigh IMAT density	1552	1171	135	0.89 (0.84, 0.95)	<0.001	0.92 (0.87, 0.98)	0.01	0.96 (0.90, 1.02)	0.18

[1] Multivariate Cox proportional hazards models were used to assess risk of incident mobility limitation for each SD increment in BMI and adipose measure. Model 1 was adjusted for age, race, and study site. Model 2 was adjusted as for model 1 and for education, smoking status, prevalent disease, physical activity, midlife weight, and pain. Model 3 was adjusted as for model 2 and for BMI. Health ABC, Health, Aging, and Body Composition Study; IMAT, intermuscular adipose tissue; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue.
[2] HR; 95% CI in parentheses (all such values).

TABLE 4
Associations between BMI and adipose measures at baseline and odds of poor performance after 9 y in Health ABC participants stratified by sex[1]

	n	No. with gait speed <1 m/s	Model 1	P	Model 2	P	Model 3	P
Men								
BMI	726	314	1.30 (1.11, 1.53)[2]	0.001	1.31 (1.07, 1.61)	0.01	—	—
VAT area	707	305	1.25 (1.06, 1.48)	0.008	1.20 (0.99, 1.44)	0.06	1.14 (0.92, 1.40)	0.23
Abdominal SAT area	699	299	1.30 (1.11, 1.52)	0.001	1.29 (1.06, 1.57)	0.01	1.29 (0.99, 1.67)	0.06
Thigh SAT area	714	308	1.25 (1.07, 1.47)	0.004	1.26 (1.06, 1.50)	0.008	1.22 (1.00, 1.50)	0.05
Thigh IMAT area	714	308	1.46 (1.20, 1.76)	<0.001	1.54 (1.22, 1.93)	<0.001	1.54 (1.18, 2.02)	0.001
VAT density	706	305	0.87 (0.72, 1.05)	0.15	0.93 (0.77, 1.14)	0.50	0.99 (0.80, 1.23)	0.91
Abdominal SAT density	697	299	0.95 (0.79, 1.14)	0.57	1.02 (0.84, 1.23)	0.87	1.06 (0.87, 1.30)	0.55
Thigh SAT density	714	308	0.87 (0.74, 1.03)	0.11	0.86 (0.72, 1.03)	0.10	0.88 (0.73, 1.05)	0.16
Thigh IMAT density	714	308	0.78 (0.66, 0.92)	0.003	0.78 (0.65, 0.93)	0.006	0.80 (0.67, 0.97)	0.02
Women								
BMI	843	467	1.71 (1.45, 2.02)	<0.001	1.41 (1.13, 1.76)	0.002	—	—
VAT area	816	451	1.47 (1.24, 1.73)	<0.001	1.12 (0.93, 1.36)	0.24	0.96 (0.77, 1.20)	0.74
Abdominal SAT area	792	432	1.51 (1.28, 1.77)	<0.001	1.31 (1.06, 1.61)	0.01	1.07 (0.81, 1.42)	0.62
Thigh SAT area	828	456	1.46 (1.23, 1.74)	<0.001	1.30 (1.04, 1.62)	0.02	1.10 (0.84, 1.44)	0.49
Thigh IMAT area	828	456	1.66 (1.40, 1.97)	<0.001	1.36 (1.12, 1.64)	0.002	1.25 (1.01, 1.54)	0.04
VAT density	815	451	0.80 (0.68, 0.95)	0.01	0.93 (0.77, 1.12)	0.44	1.03 (0.84, 1.26)	0.81
Abdominal SAT density	789	432	1.05 (0.89, 1.23)	0.57	1.04 (0.87, 1.24)	0.71	1.08 (0.90, 1.30)	0.41
Thigh SAT density	828	456	1.05 (0.90, 1.22)	0.55	1.00 (0.84, 1.18)	0.96	1.00 (0.84, 1.19)	0.97
Thigh IMAT density	828	456	0.88 (0.76, 1.03)	0.11	0.92 (0.78, 1.09)	0.35	0.96 (0.81, 1.14)	0.66

[1] Multivariate logistic regression models were used to assess odds of poor performance for each SD increment in BMI and adipose measure. Model 1 was adjusted for age, race, and study site. Model 2 was adjusted as for model 1 and for education, smoking status, prevalent disease, physical activity, midlife weight, and pain. Model 3 was adjusted as for model 2 and for BMI. Health ABC, Health, Aging, and Body Composition Study; IMAT, intermuscular adipose tissue; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue.

[2] OR; 95% CI in parentheses (all such values).

poor performance, although risk relations were less convincing than for adipose area and generally not independent of BMI.

Our findings align with those of previous studies on obesity and risk of disability or limitation in older adults (8–10, 19). Of the measures assessed in the current study, thigh IMAT area and BMI appeared to be particularly strong risk factors for mobility limitation and poor performance. The positive association between IMAT area and mobility limitation was previously reported in the Health ABC after 2.5 y of follow-up (20). Our data suggest that IMAT continues to be an important risk factor for future mobility limitation even into old age (participants 83–92 y old after follow-up). Similarly, risk relations persisted for BMI despite BMI generally being a weaker correlate of adiposity in old age (21). Also of note, thigh SAT area was positively associated with risk of mobility limitation in women and poor performance in men and women. This result contrasts with the notion that a greater leg fat accumulation may have metabolic and cardioprotective properties (22–24) that reflect a low fatty acid release and more-favorable inflammatory profile relative to abdominal and portal adipose tissue (25–28). The potential opposing risk relations between thigh SAT and health outcomes should be examined in future research.

Although obesity is a well-established risk factor for disability, less is known regarding potential mechanisms. Obesity is a risk factor for many chronic diseases (ie, diabetes, heart disease, and osteoarthritis) that would be expected to contribute to disability; however, relations between adipose tissue and mobility limitation persisted with adjustment for prevalent disease in our study and other studies (29). Previous studies have suggested that a direct physical burden (strain on the skeletal system) (30), adipose infiltration of organs such as in liver and muscle (20), inflam-

mation (31), and general deconditioning (32) may contribute to relations between obesity and disability. In our analysis, adjustment for indicators of deconditioning (physical activity and knee pain) did not attenuate associations between BMI, adipose area, and limitation or function, which suggested that these factors incompletely explain risk.

To our knowledge, this is the first examination of adipose tissue density in relation to functional outcomes, although parallels can be drawn with studies of muscle density that also assessed from the HU of computed tomography images. Studies within the Health ABC (20, 33) and other cohorts (34) have suggested associations between muscle density, strength, and a decline in performance, possibly more so than muscle area. These associations are in contrast with our results, which suggested stronger relations with BMI and adipose area than adipose tissue density. It is unclear why adipose tissue and muscle densities appear to have divergent relations. However, the fact that BMI and adipose tissue area were more consistently related to mobility limitation and poor performance provides a potential avenue for intervention because the modification of BMI and adipose depots may be more clinically feasible. Indeed, clinical trials of weight loss in older adults have suggested that weight and fat loss can improve mobility (35, 36).

Potential mechanisms that underlie relationships between adipose tissue density and mobility limitation are unclear because there are few studies of computed tomography–measured adipose density. Our previous work suggested that the density of adipose tissue is not related to inflammation but is positively related to adiponectin (13). Higher adiponectin in older adults has been associated with greater physical disability (37), but this variable likely represents a marker of disability not a causal relation.

Rather, it appears that associations between adipose tissue density and risk of mobility disability largely reflect risk attributable to heavy BMI. Adipose tissue density was inversely correlated with BMI, and risk estimates for mobility limitation and poor performance were generally attenuated with adjustment for BMI. Additional research into clinical and biological correlates of adipose tissue density may provide additional insight into relations.

A strength of the study was that the population was initially free from mobility limitation, which minimized potential reverse causation from preexisting mobility limitation. Additional strengths included the biracial population, frequent assessment of mobility limitation over an extended follow-up period, and availability of computed tomography images, which permitted the precise assessment of abdominal and thigh adipose depots and adipose tissue density. We also used 2 outcomes related to mobility limitation and function. Risk associations with an objective measure of function showed markedly similar relations as self-reported mobility limitation. However, the study cohort was restricted to initially well-functioning individuals and excluded individuals older than 79 y. Associations may differ for less-healthy populations or different ages. We also used indicators of disability that were centered on lower extremity function, and it is possible our results may have varied with more-global measures of disability.

In conclusion, more than three-quarters of participants developed mobility limitation and upwards of 40% of participants had poor performance despite being initially well functioning. These results show the importance of identifying factors that place an individual at increased risk of future limitation. Our results show that, despite controversy over BMI as an indicator of overall adiposity in old age (21), heavier BMI continues to be associated with risk of mobility limitation and performance into late life. IMAT is also robustly associated with risk, suggesting that an investigation into interventions that target IMAT (38) in addition to the promotion of healthy body weight may be warranted.

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