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Abdominal body composition measured by quantitative computed tomography and risk of non-spine fractures: the Osteoporotic Fractures in Men (MrOS) study

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Abstract

The association of abdominal adiposity and muscle composition with incident fracture is unclear, especially in older men. Therefore, we examined the relationship of subcutaneous adipose tissue (SAT), visceral adipose tissue (VAT), abdominal intermuscular adipose tissue (IMAT) and muscle volume with incident non-spine fractures among 749 men aged 65 and older. A case-cohort study design was used with a total of 252 fracture cases and 497 non-cases. We measured volumes (cm³) of adipose and muscle tissues obtained from quantitative computed tomography scan at the L4–L5 intervertebral space. Three groups of muscle and IMAT were evaluated: total abdominal, psoas and paraspinous. Cox proportional hazards regression with a robust variance estimator was used to estimate the hazard ratio (HR) of non-spine fractures per standard deviation (SD) increase in the abdominal body composition measures. The mean age among men in the random subcohort was 74.2±6.1 years and the average follow-up time was 5.2±1.1 years. After adjusting for age, race, clinic site, percent body fat and femoral neck bone mineral density (BMD), no significant relationship was found between incident fractures and SAT or VAT. One SD increase in muscle volume at the psoas, but not paraspinous, was associated with 28% lower fracture risk (95% CI=0.55–0.95). When IMAT models were further adjusted for corresponding muscle volumes, only abdominal IMAT was significantly associated with fracture risk (HR=1.30, 95% CI=1.04–1.63). Our findings suggest that lower total psoas muscle volume and higher IMAT of the total abdominal muscle contribute to higher fracture risk in older men independent of BMD.

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Keywords

fracture; adipose tissue; muscle; intermuscular fat

Introduction

Osteoporotic fractures are a major public health concern due to the consequent immobility and morbidity. Although osteoporosis and osteoporotic fractures are more prevalent among postmenopausal women, hip fracture in men results in higher mortality compared to women [1]. The number of fractures in US men is expected to double in the next 25 years, largely due to the increase in elderly population [2]. Although appreciation of the impact of osteoporosis and fracture among men is growing, further understanding is needed on the biologic basis of osteoporosis and fracture in this population. Abdominal adiposity has been shown to be associated with increased mortality and risk for several aging-related chronic diseases [3–5]. Studies examining the association between abdominal adiposity and bone have mainly focused on bone mineral density (BMD), and little is known about its association with fracture. Changes in abdominal body composition could influence fracture risk through adverse effects on skeletal loading patterns, alterations in metabolic activity that contribute to bone loss, or on physical functioning that may increase fall risk.

In men, changes in body composition associated with age or across age groups include, but are not limited to, decreased hip bone mineral density [6] and abdominal muscle area [7], increased overall body fat mass [8,9], and infiltration of adipose tissue into skeletal muscle [10,11]. Moreover, the distribution of abdominal adipose tissues shifts more toward visceral adipose tissue (VAT) deposition than subcutaneous adipose tissue (SAT) with aging [12,13]. This shift, in part, contributes to the observed detrimental effect of abdominal adiposity on mortality and age-related chronic diseases [4,14,15]. However, the relation of abdominal body composition to risk of fractures among older men is unknown.

Limited studies have evaluated the role of regional adiposity on osteoporosis or fracture. Smaller amounts of abdominal fat, measured by dual energy X-ray absorptiometry (DXA), was found to be related to an increased risk of hip fracture in older women but not men; however, the association disappeared after adjusting for femoral neck BMD [16]. Although DXA is reliable in determining abdominal obesity, it is unable to distinguish different types of adipose tissues and muscles. Quantitative computed tomography (QCT) permits the detailed assessment of distinct abdominal muscle and adipose tissues [12,17,18]. It is considered a gold standard for assessing adipose tissue distribution in the subcutaneous and visceral compartments and provides valid measurements of skeletal muscles. Studies using direct measurement of VAT have found a consistent negative association between VAT and BMD [19–21], as well as evidence supporting the detrimental role of fatty infiltration of muscles (intermuscular adipose tissue, IMAT) at the thigh and pelvis, on fractures [22,23].

To investigate the relation of abdominal adipose tissue distribution and muscle characteristics to non-spine fracture risk among older men, we conducted a case-cohort study using abdominal body composition measures derived from QCT scans. We tested the hypothesis that fracture risk would increase with greater amounts of SAT, VAT and IMAT, and would decrease with greater muscle volume. We also posited that lower fracture risk would be more strongly associated with psoas muscle volume than with paraspinal muscle volume, because psoas muscles are involved in hip rotation and therefore lower extremity function.

Methods

Study population

The Osteoporotic Fractures in Men (MrOS) study is a prospective cohort designed to identify risk factors associated with osteoporosis and osteoporotic fractures in men. From March 2000 to April 2002, 5,994 older men were recruited from 6 sites across the US, including: Birmingham, AL, Minneapolis, MN, Palo Alto, CA, Pittsburgh, PA, Portland, OR, and San Diego, CA. Recruitment was accomplished primarily through targeted mailings based on motor vehicle registration, voter registration, and Veterans Administration database. To be eligible for the MrOS study, men needed to be age 65 and older, be able to walk without assistance from another person, and have had no bilateral hip replacement. Details of the study have been published previously [24,25]. Following the baseline visit, information on self-reported non-spine fractures was assessed every 4 months by postcard or telephone. The response rate to these questionnaires exceeded 99% in surviving men. All reported fractures are centrally adjudicated and validated by a physician using radiology or operative reports. The anatomic location and level of trauma associated with the fracture are recorded. This analysis included both trauma and non-trauma fractures. The institutional review board at each center approved the study protocol. All participants gave written informed consent.

At baseline, 3,786 men were referred for QCT scans of the hip, lumbar spine and abdomen. Characteristics of the MrOS QCT cohort have been described previously [26]. In brief, men referred to QCT scans were slightly younger (73.5 vs. 73.8 yrs), shorter in height (173.8 vs. 174.0 cm), more likely to be of non-white race (12.9% vs. 6.6%), and less likely to have hypertension (41.7% vs. 45.3%) and cancer (28.4% vs. 30.5%). There is no difference in weight, BMI, hip BMD, fracture history, and history of fall in the past 12 months. Abdominal scans were obtained using a standardized protocol which specified scanning from the mid-L3 to the mid-L5 vertebra at settings of 80 kVp, 140 mA, 5-mm slice thickness, and 512 × 512 matrix in spiral reconstruction mode. Participants were scanned in the supine position with calibration standards of known hydroxyapatite concentrations (150, 75, and 0 mg/cm³).

Sample selection

For the present study, we used a case-cohort design among men who had been referred for QCT scans at baseline (Figure 1). From these participants, we selected all incident non-spine fracture cases confirmed as of June 30th, 2006 (n=294). To serve as the comparison subcohort, we randomly selected 667 men who had been referred for QCT scans at baseline, without knowledge of their subsequent fracture status. In total, our selection procedure resulted in 902 unique participants whose QCT scans were then retrieved for abdominal body composition image processing. Of 902 participants selected for this case-cohort study, 153 scans were not eligible for imaging processing due to missing images, beam hardening artifact obscured the fascial borders of the skeletal muscle groups, the participant moved during the scan, or the calibration standard or any part of the abdomen was outside the field of view (Figure1). The current analysis includes 497 non-cases from the subcohort and a total of 252 cases (49 from the subcohort).

Measurements of abdominal adipose tissues and muscle from QCT

Image processing was completed by two readers at the Oregon Health & Science University using a standardized protocol. Abdominal QCT scans were processed on workstations equipped with sensitive digitizing pens (Wacom Technology Corp., Vancouver, WA) and Analyze Biomedical Imaging software (AnalyzeDirect Inc., Overland Park, KS). A scan was considered ineligible for for reasons described above. In eligible scans, the 5-mm slice at

L4–5 intervertebral space was identified, verified on the scout view, and extracted from the scan series for processing. To account for variability in image attenuation across the different scanners, the native Hounsfield units (HU) were rescaled so that an average of 0 HU was obtained for the portion of the calibration standard with 0mg/cm³ hydroxyapatite.

Voxels within the slice were separated into color-coded objects containing adipose tissue (AT) (–190 to –30 HU) [27,28] and muscle (0 to 100 HU) [17,18]. Voxels from –29 to –1 HU, 101 to 144 HU and 145 HU (bone) were not deleted. The fascial borders of the skeletal muscles were traced manually and skeletal muscle was then temporarily segmented out of the image. A closed contour was then drawn in the space created by removal of the skeletal muscle. SAT was defined with voxels outside of the contour and with HU in the range for adipose tissue. VAT was defined as voxels within the contour and with HU in the adipose tissue range. In the image created from muscle segmentation, voxels within the vertebral body or iliac crest with HU in the muscle or AT ranges were inactivated so as not to erroneously include these in our measurements. Groups representing all abdominal muscles, psoas muscles, and paraspinal muscles were then defined from the remaining voxels with HU in the ranges for muscle or for adipose tissue. For each tissue of interest, volumes (cm³) were computed automatically by the software as the number of voxels multiplied by the voxel volume. Total volumes of all abdominal skeletal muscle, and of the psoas and paraspinal muscle groups individually, were computed as the sum of the muscle tissue and IMAT volumes [17]. Figure 2 shows the morphologically discrete tissues produced at the completion of image processing. Inter- and intra-reader reliability was monitored throughout image processing with intraclass correlations coefficients (ICC). Final ICCs were all 0.94 for each tissue measure.

Other baseline measures

At baseline, all participants completed a self-administered questionnaire, which included age, race/ethnicity, self-reported physician diagnoses including diabetes, self-reported health status and lifestyle questions. Height was measured on wall-mounted Harpenden stadiometers, and weight was measured on standard balance beam or digital scales using standard protocols. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m²). Grip strength (kg) was measured twice by a hand held Dynamometer (Jamar) in both the right and left hands and the average grip strength was computed. BMD was measured using DXA (QDR 4500W, Hologic Inc., Waltham, MA). All measurements of hip BMD were made on the right hip, unless the subject reported a right hip replacement or metal objects in the right leg, in which case the left hip was measured. Total body fat mass, total body lean mass, and percent body fat mass were also obtained using whole body DXA. We also included measurements of physical performance (6-meter walking speed and time to complete 5 chair stands). Physical activity was assessed with the Physical Activity Scale for the Elderly (PASE) with higher scores indicating a greater level of activity.

Statistical methods

The current analysis comprised valid QCT abdominal body composition scans from 749 participants (252 non-spine fracture cases). We compared baseline characteristics and QCT abdominal body composition measures between men who experienced a non-spine fracture (cases) and those who remained fracture free (non-cases) using T test for normally distributed continuous variables, Wilcoxon rank test for not normally-distributed continuous variable, and Chi-square test for categorical variables. Within the subcohort, we computed crude and age-adjusted Pearson correlation coefficients for all body composition measures (including anthropometric, DXA and QCT measures) except for psoas IMAT. Due to the skewed distribution of psoas IMAT, Spearman correlation coefficients were estimated. In

the entire case-cohort sample, Cox proportional hazards regression with Prentice weights [29] was used to estimate associations of individual abdominal body composition parameters with risk of incident non-spine fractures. Hazard ratios (HR) and their 95% confidence intervals (CI) were estimated per standard deviation (SD) increase in the corresponding QCT abdominal parameters. Separate models were run for each QCT abdominal parameter as the independent variable. Variables which were significantly different between men with and without fractures were included in the multivariable models. These included age, race, weight, BMI, femoral neck BMD, grip strength, and fracture history. In addition, percent body fat mass and diabetes were also included due to their potential associations with abdominal AT and muscle measures. We fit these variables sequentially into the models to evaluate their effects on the HR estimates. For example, the base multivariate model included age, race and clinic site. Either weight, BMI or percent body fat were further added individually to evaluate the association between abdominal body composition measures and non-spine fractures independent of overall body composition. We then added femoral neck BMD to the model to test whether the associations were attenuated after controlling for the effect of BMD on fracture. In our final modeling step, we included grip strength, fracture history and diabetes due to their significant different prevalence by fracture status and important role in the relationship between body composition and fracture. All statistical analyses were performed with SAS software (SAS Institute, Inc., Cary, NC).

Results

Baseline characteristics and QCT measures by non-spine fracture status

Fracture types among the 252 incident non-spine fracture cases are 53 ribs/chest/sternum, 45 hip/pelvis, 23 wrist, 20 legs, 19 clavicle/scapula, 19 arm, 19 ankle, 10 foot, 9 hands and 35 others. Compared to non-cases, men who experienced incident non-spine fractures were older, and had lower body weight, BMI, femoral neck BMD, and grip strength (Table 1). Compared to non-cases, fracture cases were also more likely to be Caucasian and to have had a fracture history prior to the baseline visit. Overall, QCT abdominal body composition measures were similarly distributed in the two groups of men. However, men with non-spine fractures had significantly lower total psoas muscle and IMAT volumes, but a higher paraspinal IMAT volume, than men without fractures.

Correlations of body size, DXA and QCT parameters

There was considerable variation in correlations between the abdominal body composition and total body composition measures (Table 2). Both SAT and VAT volumes were positively correlated with total body adiposity measures (correlation coefficients ranging from 0.43 to 0.78). Total abdominal muscle volume was moderately correlated with weight and BMI, but not correlated with fat mass measures. Total psoas and paraspinal muscle volumes were weakly correlated with most total body measures. The IMAT measures were moderately to strongly correlated with the total body measures (ranged from 0.10 to 0.57), although the degree of correlation was lower for paraspinal IMAT.

Correlations among QCT parameters

Correlations among QCT abdominal measures also varied in magnitude (Table 3). SAT and VAT volumes were modestly correlated ($r=0.39$). Neither of the two AT measures was strongly correlated with the total muscle volumes ($p>0.05$), but both were weakly correlated with the IMAT volumes (ranging from 0.11 to 0.36). The total muscle volumes were strongly to moderately correlated, with the strongest correlation observed between total muscle volumes of abdominal and psoas ($r=0.66$). Psoas and paraspinal IMAT volumes were also highly correlated with abdominal IMAT volume ($r=0.73$ and 0.65), but the correlation between psoas and paraspinal IMAT volumes was relatively weak ($r=0.27$).

Partial correlations adjusted for age showed similar patterns for correlations between QCT abdominal measures and overall body composition measures, and among QCT abdominal measures (data not shown).

Multivariable analyses

The associations of QCT abdominal measures with incident non-spine fractures are shown in table 4. Hazard ratios for non-spine fractures are expressed per SD increase in QCT measures. We present result with adjustment for percent body fat, because similar results were found when replacing percent body fat with weight, BMI or total body fat mass. No significant associations were observed for the associations of SAT or VAT with fractures. Total abdominal muscle volume was not associated with non-spine fractures. However, larger total psoas muscle volume was significantly associated with lower risk of non-spine fracture with a magnitude of approximately 30% reduction per SD. Further adjustments for percent body fat, femoral neck BMD, grip strength, fracture history and diabetes did not significantly affect the association (model 2, 3 and 4). Greater total paraspinal muscle volume was weakly associated with increased fracture. For IMAT volumes, each SD increase was associated with increased fracture risk for abdominal (30%) and paraspinal (19%) regions in model 3 and model 4. However, when model was controlled for corresponding total muscle volume (model 5), the positive and significant relationship for paraspinal IMAT was slightly attenuated (HR=1.16, 95% CI: 0.94– 1.44). Psoas IMAT appeared to be associated with lower non-spine fracture risk, but the association was not independent of femoral neck BMD.

For all the multivariable models, additional adjustment for other physical performance measures, physical activity, back pain, and history of falls were considered due to their potential confounding effect. However, these factors did not materially alter the results shown in Table 4 (data not shown).

Discussion

Our study aimed to evaluate two specific novel non-skeletal risk factors for fractures: regional abdominal adipose distribution and skeletal muscle composition. Previous studies have reported a protective effect of greater thigh/leg muscle on fracture likely acting via lower fall risk, stronger muscle strength and better physical performance [10,30,31]. Greater body weight, often accompanied with greater adiposity, has in the past been thought to be protective against osteoporosis due to chronic mechanical overloading and sex steroid hormone stimulation. However, obesity has been linked to increased non-spine fracture risk in older men when BMD is held constant [32]. Diabetic individuals, often accompanied by greater body fat, have shown to have greater IMAT [15,33] and fracture risk [34] than their non-diabetic counterparts. A growing body of literature also reports the importance of muscle volume and fatty infiltration of muscle on peripheral neuropathy [35] and fracture risk [22,23,36], likely interacting through mechanisms related to compromised physical performance and/or altered metabolic function. However, very little is known about the associations of abdominal adiposity and muscle on skeletal health, and whether the associations differ by specific adipose depots or muscle groups in these regions of interest.

Psoas muscle

A reduced risk of non-spine fractures with larger total psoas muscle, but not paraspinal muscle was observed in our study. Recent studies among older adults have also reported a positive association of greater skeletal muscle mass at the thigh with muscle strength, physical performance and mobility [10,30,31], which may contribute to lower fall risk and consequently prevent fracture. However, according to the different mechanical function, the

relationship of non-spine fractures with psoas and paraspinal muscles might be different than that for skeletal muscle at the thigh or leg. The psoas muscle spans from the trunk to the hip, and it is thought to be a hip flexor. Its function to flex the hip when the leg is fixed (and vice versa) and thus plays an important role in walking. Moreover, the psoas muscle is among the primary muscles that are meant to move the leg forward as quickly as possible to make a recovery step to prevent a fall. Therefore, our observation of greater total psoas muscle volume in fracture risk reduction may act through better fall prevention. It is also possible that greater psoas muscle volume reflects greater thigh/leg muscle mass among our study participants, and ultimately leads to lower fracture risk via lower fall risk, stronger muscle strength and better physical performance [10,30,31]. However, in our study, further adjusting our multivariable models for falls, lower back pain, time to complete 5 chair stands, walking speed or PASE did not materially change estimates. Future studies might include a direct test of reaction time to investigate whether it attenuates the association between psoas muscle and fracture.

IMAT is considered a determinant of muscle quality [10]. Emerging evidence has linked greater IMAT to compromised muscle strength [10], physical performance [30,31,37], lower back pain [37,38], severe peripheral neuropathy [35] and an increased likelihood of fractures [22,23,36]. In the current analysis, men with incident fractures appeared to have a lower psoas IMAT volume, but greater total abdominal and paraspinal IMAT, than those without fracture (table 1). The effect of this small difference in psoas IMAT (0.1 cm^3) on fracture might be trivial or might not be independent. We consistently observed greater psoas IMAT volume with lower fracture risk; however, this association was not statistically significant once BMD was taken into account (model 3, table 4). IMAT volume at the psoas was approximately one tenth of total psoas muscle volume and 7% of the total abdominal IMAT volume; therefore, the small variation in psoas IMAT volume might not contribute greatly to fracture risk as paraspinal and total abdominal IMAT.

Paraspinal muscle

On the other hand, paraspinal muscle, often considered the major back muscle, provides support to the spine and controls movement of the spine. A study by Sinaki and colleagues suggested that stronger back muscles may help in reducing vertebral fracture [39]. Another study showed that elderly women with vertebral fracture had better paraspinal muscle control than those without vertebral fracture [40]. In our study, greater total paraspinal muscle volume was weakly associated with higher non-spine fractures but this was only significant after adjusting for grip strength, fracture history and diabetes. The outcome measurement of non-spine fractures may not be ideal to evaluate the association between paraspinal muscle and fracture since the functions of paraspinal muscle are spine-related. Future studies should examine the association between paraspinal muscle and vertebral fracture.

Nonetheless, the effect of paraspinal IMAT on fracture might not highly depend on the type of fracture being examined. Opposite to what we found for psoas, paraspinal muscle was infiltrated with more adipose tissue (10% for psoas vs. 35% for paraspinal) and the poor quality of paraspinal muscle was significantly associated with greater fracture risk independent of age, body composition and BMD in our study. Further adjustment of prior fracture history, grip strength and diabetes did not change the association. Back pain, fall history, physical performance (including time to complete 5 chair stands, walking speed and PASE) also did not explain the association between paraspinal IMAT and fracture (data not shown). However, what explained the positive association between paraspinal IMAT and fracture might be greater paraspinal muscle volume (model 5), indicating that this relationship might partly reflect the association between total paraspinal muscle and fracture.

Total abdominal muscle

We observed no association between total abdominal muscle volume and non-spine fractures in our study. However, greater total abdominal IMAT was significantly related to increased non-spine fracture in all models. The adjustment of fracture history, physical performance, and diabetes did not attenuate the association between abdominal IMAT and fracture. Due to the known effect of thiazolidinediones (TZD) on fracture among diabetic individuals, additional control for the use of TZD was introduced (data not shown). With only 12 participants reporting usage of TZD, results were essentially unchanged. Greater fatty infiltration of the total abdominal muscle may also reflect greater infiltration of thigh muscle, which has been linked to increased fracture risk [22,23,36]. However, the mechanism underlying the relationship between IMAT and fracture remained unclear. A recent study by Schafer et al. reported that fat infiltration is associated with higher fracture risk, but diabetes fails to explain the increased fracture risk [36]. Further investigation is needed to understand how IMAT affects skeletal health.

SAT and VAT

The relationship between SAT and skeletal traits is controversial. Our study found no association between SAT and non-spine fracture, while others found a positive association of SAT with skeletal health [19,20,41], including inverse associations with bone mass and BMD [19,20,41]. However, this association might not be independent of body weight [19]. SAT was also found to be inversely associated with bone mass and BMD in other studies. The link between VAT and skeletal outcomes is also inconsistent, and is highly dependent on the accuracy of VAT assessment. Studies using surrogate measures of VAT, such as waist-hip-ratio, waist circumference and metabolic syndrome, have reported inconsistent relationships with BMD: null [19], positive [16,20] and negative [19,42] associations have each been reported. In addition, a higher surrogate-VAT measure was also related to lower fracture risk [16,20,42,43], but this association disappeared after controlling for BMD [16,43]. However, when VAT was assessed by CT or MRI, a detrimental effect on bone density, mass and geometry was consistently found [19–21,41,44]. It is unclear whether the same effect applies to fracture outcomes since information is scarce. In our study, VAT appeared to be protective against fractures, but the effect was not significant in all models.

As Lee MJ and colleagues pointed out, adipose depots differ in cellular composition and physiology levels, and these differences influence their phenotypic properties[45]. SAT and VAT differs in their functions and their associated adverse health outcomes may differ in part due to greater expression of pro-inflammatory cytokines and lymphocytes in VAT than in SAT[45]. VAT in particular has been associated with greater mortality and higher risk of cardiovascular diseases [4,46]. Compared to SAT and VAT, IMAT lies between different muscle groups and accounts for a relatively small proportion of the total body adiposity. Therefore, its function is thought to be specialized to its neighboring tissues[18]. Although IMAT has been linked to muscle strength [10,30]and metabolic disorders [47,48]; its cellular composition remains unclear. Further investigation into the cellular composition and metabolic response of IMAT may provide us a better understanding of the underlying mechanisms for the currently observed associations between IMAT and various health outcomes.

Our study utilized QCT to obtain abdominal body composition, which enabled us to evaluate the effect of different adipose tissue depots and skeletal muscle groups on non-spine fracture risk. With the case-cohort design, we were able to efficiently evaluate the longitudinal relationship between non-spine fractures and abdominal adipose and muscle composition, which has not been studied on a larger scale. Our study also has a few limitations. Obesity is known to affect the speed of X-ray wave through the body, and will

likely introduce an artifact to the QCT scan. When comparing body composition between men with valid and invalid scans, we found that men with invalid scans were younger, had greater BMI and total body fat, and were more likely to be obese. This may underestimate the effect of abdominal body composition on fractures. In addition, hip fracture is the most devastating type of fracture that leads to increased mortality, hospitalization, immobility, and dependency. However, we are unable to perform this analysis exclusively on hip fracture due to small sample size. At last, the present study included male participants, who are relatively under-studied in the area of osteoporosis and fracture compared to women. Nonetheless, results of our study may not be generalizable to women.

In summary, total abdominal IMAT volume, but not total abdominal muscle volume, was associated with increased incident non-spine fractures risk among older men independent of age, race, percent body fat, femoral neck BMD, muscle volume, grip strength, fracture history and diabetes. By separating abdominal muscles into psoas and paraspinal muscles, a protective role of total psoas muscles was found. Muscle composition is clearly related to fracture risk and its association with fracture varies across muscle groups, likely according to their specific mechanical function. Understanding these relationships may be important in targeting specific interventions for fracture prevention.

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Fig1.
Case-cohort design for the MrOS QCT abdominal body composition and incident non-spine fracture study

Fig2.

Illustration of abdominal body composition measures that result from image processing procedures established for the MrOS abdominal scans. Panel a: Subcutaneous adipose tissue (SAT) lies between the dermis and the fascia of the abdominal muscles. Panel b: Visceral adipose tissue (VAT) forms around the internal organs in the visceral cavity. Panel c: Abdominal skeletal muscle is colored pink and the intermuscular adipose tissue (IMAT) is colored brown. Psoas muscle (PS) and parapsinal muscle groups (PL) are also shown

Table 1
Comparison of baseline characteristics between non-case men in the subcohort and all cases (with valid scan onl)

Variables	Non-cases in subcohort (n=497)	mean±SD	All cases (n=252)	mean±SD
Age	74.1±5.8		75.3±6.3 *	
Race (white)	89		94 *	
Height (cm)	173.8±7.0		173.5±7.0	
Weight (kg)	81.1±11.4		78.9±11.0 *	
BMI (kg/m ²)	26.8±3.2		26.2±3.2 *	
Total body fat mass (kg)	20.9±6.1		20.1±6.5	
Femoral neck BMD (g/cm ²)	0.78±0.13		0.73±0.12 *	
Percent body fat (%)	25.9±5.1		25.5±5.9	
Average grip strength (kg)	38.3±7.9		36.7±8.5 *	
Self-reported medical & behavioral history				
	Percent (%)		Percent (%)	
Diabetes	11.0		11.1	
Stroke	7.0		7.5	
Hypertension	43.5		36.9	
Heart attack	15.7		14.3	
Cancer	28.8		34.1	
Fracture history	50.9		69.4 *	
Lower back pain in the past 12 month	61.8		67.3	
Self-rated excellent health compare with others at the same age	88.1		85.3	
Ever smoked	60.6		59.5	
QCT body composition measures				
	mean±SD		mean±SD	
SAT volume (cm ³)	94.0±32.4		89.8±33.2	
VAT volume (cm ³)	67.8±27.4		65.1±27.2	
Total muscle volume (cm ³); muscle + IMAT				
Total abdominal	63.7±8.2		63.3±8.5	
Psoas	11.0±2.6		10.5±2.7 *	

Variables	Non-cases in subcohort (n=497) mean±SD	All cases (n=252) mean±SD
Paraspinal	18.5±3.8	19.0±4.1
IMAT volume (cm ³)		
Total abdominal	15.8±6.0	16.2±6.8
Psoas	1.1±0.9	1.0±0.9 *
Parapsinal	6.4±2.6	7.0±3.0 *

* p-value <0.05

Table 2

Correlations between volumes (cm³) of QCT abdominal body composition parameters and weight, BMI, and fat mass within subcohort^{##}

	SAT	VAT	Total abdominal muscle	Total psoas muscle	Total paraspinal muscle	Abdominal IMAT	Psoas IMAT	Paraspinal IMAT
Weight	0.61	0.43	0.32	0.03	0.16	0.57	0.47	0.22
BMI	0.68	0.47	0.22	-0.06	-0.03	0.52	0.47	0.10
DXA total fat mass	0.78	0.56	0.09	- 0.13	0.07	0.60	0.44	0.27
DXA percent total fat	0.75	0.56	-0.08	- 0.22	<-0.01	0.50	0.34	0.26

Bold : p-values < 0.05

[¶]Correlation coefficients reported are Pearson coefficients, except for psoas IMAT where Spearman correlation was estimated.

[#]Results for age-adjusted correlations yielded similar correlation coefficients and significance level

Table 3

Unadjusted correlation among volumes (cm³) of QCT abdominal body composition measures within subcohort[†]

	VAT	Total abdominal muscle	Total psoas muscle	Total paraspinal muscle	Abdominal IMAT	Psoas IMAT	Paraspinal IMAT
SAT	0.39	0.19	0.05	0.05	0.29	0.17	0.11
VAT		0.18	-0.02	0.15	0.36	0.26	0.25
Total abdominal muscle			0.66	0.36	-0.04	-0.23	0.02
Total psoas muscle				0.29	-0.38	-0.50	-0.14
Total paraspinal muscle					0.11	-0.22	0.46
Abdominal IMAT						0.72	0.65
Psoas IMAT							0.27

Bold : p-values < 0.05

[†]Correlation coefficients reported are Pearson coefficients, except for psoas IMAT where Spearman correlation was estimated.

[#]Results for age-adjusted correlations yielded similar correlation coefficients and significance level

Table 4

HR (95% CI) for non-spine fractures per SD increase in QCT abdominal body composition measures

	Mean ± SD	Model 1	Model 2	Model 3	Model 4	Model 5
SAT volume	92.6 ± 32.7	0.90 (0.77, 1.07)	0.93 (0.71, 1.20)	1.02 (0.78, 1.34)	1.03 (0.78, 1.37)	-
VAT volume	66.9 ± 27.3	0.86 (0.73, 1.02)	0.84 (0.68, 1.04)	0.87 (0.70, 1.08)	0.88 (0.70, 1.10)	-
Total muscle volume (muscle tissue + IMAT)						
Abdominal	63.5 ± 8.3	0.97 (0.78, 1.22)	0.97 (0.78, 1.21)	1.08 (0.86, 1.36)	1.06 (0.84, 1.34)	-
Psoas	10.8 ± 2.7	0.73 (0.57, 0.94)	0.67 (0.52, 0.88)	0.72 (0.55, 0.95)	0.69 (0.52, 0.92)	-
Paraspinal	18.7 ± 3.9	1.17 (0.99, 1.40)	1.17 (0.98, 1.40)	1.17 (0.98, 1.40)	1.20 (1.00, 1.45)	-
Muscle IMAT volume						
Abdominal	16.0 ± 6.3	1.09 (0.90, 1.32)	1.24 (0.97, 1.53)	1.30 (1.04, 1.63)	1.33 (1.05, 1.69)	1.36 (1.06, 1.74)
Psoas	1.1 ± 0.9	0.76 (0.60, 0.96)	0.74 (0.57, 0.96)	0.83 (0.64, 1.09)	0.85 (0.64, 1.12)	0.86 (0.65, 1.15)
Paraspinal	6.6 ± 2.7	1.17 (1.00, 1.39)	1.20 (1.02, 1.41)	1.19 (1.01, 1.41)	1.21 (1.02, 1.44)	1.16 (0.94, 1.44)

Model 1: adjusted for age, race, and clinic site

Model 2: model 1 + percent body fat mass

Model 3: model 2 + femoral neck BMD

Model 4: model 3 + grip strength, fracture history, and diabetes

Model 5: model 4 + corresponding total muscle volume