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Original Article

Computerized Tomography derived psoas muscle indices in a healthy young population in the United States

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Abstract

Objective: Psoas muscle metrics from diagnostic computerized tomography (CT) scans are emerging as clinically relevant biomarkers. Most muscle metrics from the US population are from older cohorts with co-morbidities. Published reports from a young or healthy population in the United States on psoas muscle metrics optimized for age, body mass index (BMI), and sex are lacking. This study determines the psoas muscle index (PMI) and psoas muscle density (PMD) for a normal young Midwestern US population. **Methods**: Retrospective cross-sectional analysis of pre-existent abdominal non-contrast CT scans from a young (19-40 years old), Midwestern, predominately Caucasian population was conducted within Aquarius iNtuition software automatically after manual identification of the psoas muscle. Electronic medical records provided access to subject data and archived CT scans were reviewed. **Results**: From 193 (45 male, 148 female) CT scans, for males, PMI was 5.9 cm^2/m^2 (SD=1.7) and PMD 48.4 HU (SD=5.5); for females PMI was 5.4 cm^2/m^2 (SD=1.4) and PMD 48.18 HU (SD=5.5). BMI was significantly correlated with PMI and PMD for both men ($p<0.001$, $p<0.001$ respectively) and women ($p<0.001$, $p<0.001$ respectively). **Conclusion**: Psoas muscle metrics are newly generated for PMI and PMD in a healthy population, allowing for future comparison studies determining muscle status.

Keywords: Computerized Tomography Scans, Musculoskeletal Conditions, Muscle Disorders, Psoas Muscle Indexes, Spine-Low back

Introduction

Loss of muscle is known as sarcopenia and is classically seen in the elderly, though the diagnosis of Sarcopenia has evolved to broadly encompass significant loss of muscle mass or function, from any cause and at any age[1–3]. Importantly, sarcopenia is not necessarily associated with trauma, chronic medical conditions, or aging. Sarcopenia has been associated with lower activity levels and diminished quality of life, and is being increasingly validated as an independent prognostic measure in a wide variety of disease conditions. These conditions range from acute trauma to cancers, chronic disease, and general aging[1,4,5]. As the population ages and there is greater adoption of sedentary lifestyle, sarcopenia is becoming increasingly prevalent[1,6,7]. Lean muscle loss is often not clinically apparent, and particularly difficult to determine from simple weight-based anthropological assessments, making the use of more precise radiological assessments imperative[4]. CT scans are regarded as the gold standard for muscle and adipose tissue assessments due to their high accuracy, especially in the trunk area[8–11]. Importantly, CT scans show both muscle mass and quality, two essential elements in the diagnosis of sarcopenia[9].

CT scans are being performed at increasing frequencies in the United States. Routine information from diagnostic CT scan reports currently do not include the body composition, a missed opportunity to report valuable and clinically relevant body fat, bone or muscle metrics[12]. Recently,

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national guidelines have advocated for a change in the current paradigm of purely diagnostic CT scan reporting to include standardized and individualized body composition assessments[9]. Clinically, this is of importance since muscle loss can be reversed by exercise and lifestyle changes[13]. Increases in muscle area can be seen after initial loss of muscle tissue due to plasticity of muscle, making the treatment of muscle loss both highly feasible and clinically meaningful[13,14].

The evaluation of lumbar muscle area from a single axial CT scan slice at the third lumbar vertebra has been well validated to correlate with total skeletal muscle mass[3,15]. Isolation of the psoas muscle area (PMA) and height-stratified psoas muscle index (PMI) via semiautomatic tracing facilitates simplicity and has shown increased prognostic value when compared to the lumbar vertebral muscle area as determined at the third lumbar level[16,17,19]. Using specific diagnostic Hounsfield unit attenuation values for fat and muscle allows for the density and quality of the psoas muscle to be obtained[9,12].

A clear consensus for muscle indices cutoffs for clinical significance continues to be a matter of conjecture and ongoing debate. A widely accepted definition of Sarcopenia is a muscle mass two standard deviations below that of healthy adults[20], though a paucity of normal reference values complicate this definition, causing the European Working Group on Sarcopenia in Older People (EWGSOP) to note "more research is urgently needed in order to obtain good reference values," in 2010[3,16]. In 2018, when the EWGSOP reconvened, they found a lack of clear cut-off points as a key gap in the literature surrounding sarcopenia which limited diagnosis and treatment. Use of normative young adult data has been recommended for evaluation of muscle strength with a comparison approach similar to that of bone density except with sex-specific peak values. Known cutoff values to better clinically delineate sarcopenia have been determined for certain older populations and ethnicities, as well as for some disease states commonly associated with muscle loss[23–25]. However, these specific populations lack generalizability to our population and national guidelines call for the establishment of values from a normal young healthy population for more accurate comparison and easier screening of entire populations[16,26].

There are no published reports from a young or healthy population on multiparametric psoas muscle metrics that are optimized for age and sex (review of literature in PubMed, Science direct and Google scholar conducted May 2019). Moreover, body weight is known to impact muscle size, yet data is significantly absent for an increasingly overweight and obese population as the obesity epidemic continues to escalate[27]. Hence, in efforts to adequately match our sample to our patient population, a study was undertaken in a cohort of healthy young subjects regardless of Body Mass Index (BMI). The primary aim of our study was to determine age- and sex- specific psoas muscle index and density percentiles for a healthy predominately Caucasian, Midwestern US population. Our secondary objective was to detail the BMI-specific percentile distribution for young males and females. Using a healthy population to determine these values will allow for more accurate comparison and screening of patients with occult muscle loss. Following detection, targeted exercises would potentially lead to better prognosis and decreased mortality and morbidity.

Materials and Methods

This retrospective cross-sectional study was conducted at a large Midwestern university-affiliated hospital. Electronic medical records provided access to subject data and archived CT scans. All medical records of adult patients aged 19-40 with non-contrast abdominal CT scans done in the past three years (July 2015-June 2018) were reviewed. To reduce the number of variables potentially affecting measurements, only non-contrast CT scans were included and CT scans with any abnormal findings or of poor radiological quality were excluded[28,29]. The Institutional review board approved the exempt study and waiver of consent.

Study population selection and data collection

A study flowchart (Figure 1) depicts the selection of a normal healthy cohort from an initial pool of adult subjects with a previous diagnostic non-contrast abdominal CT scan to establish a cohort of healthy young eligible subjects with an eligible CT scan for analysis.

Study population selection and medical data collection

Inclusion search criteria consisted of non-pregnant adult patients 19 to 40 years. Age group was selected based on ranges selected by international guidelines and the likelihood of increased chronic disease and physiological muscle decline after age 40. Smoking is known to impact muscle loss, hence only lifetime non-smokers were included[30]. To establish a healthy cohort the presence of diagnosed chronic disease was excluded. Increased BMI was not considered to be unhealthy unless co-morbid conditions were present. All non-smokers who were alive at the end of the study period, June 2018, and without ICD codes for diabetes and hypertension in their medical records were automatically selected in chronological order as the eligible study pool. Further manual screening was conducted of each personal medical record by a board-certified Family Medicine physician to confirm absence of concomitant acute or chronic health conditions. The list of chronic health conditions included congenital disorders, neurological disease, musculoskeletal conditions, endocrine abnormalities, cerebrovascular or cardiovascular disease, all cancer, anorexia or malnutrition and liver disease, among others. Polysubstance abuse, marijuana use, chronic alcoholism or diagnosed alcohol or substance abuse were further exclusions. Medication lists were reviewed for any long-term prescribed medication use, and included diabetes or hypertension medications, asthma therapy with inhaled

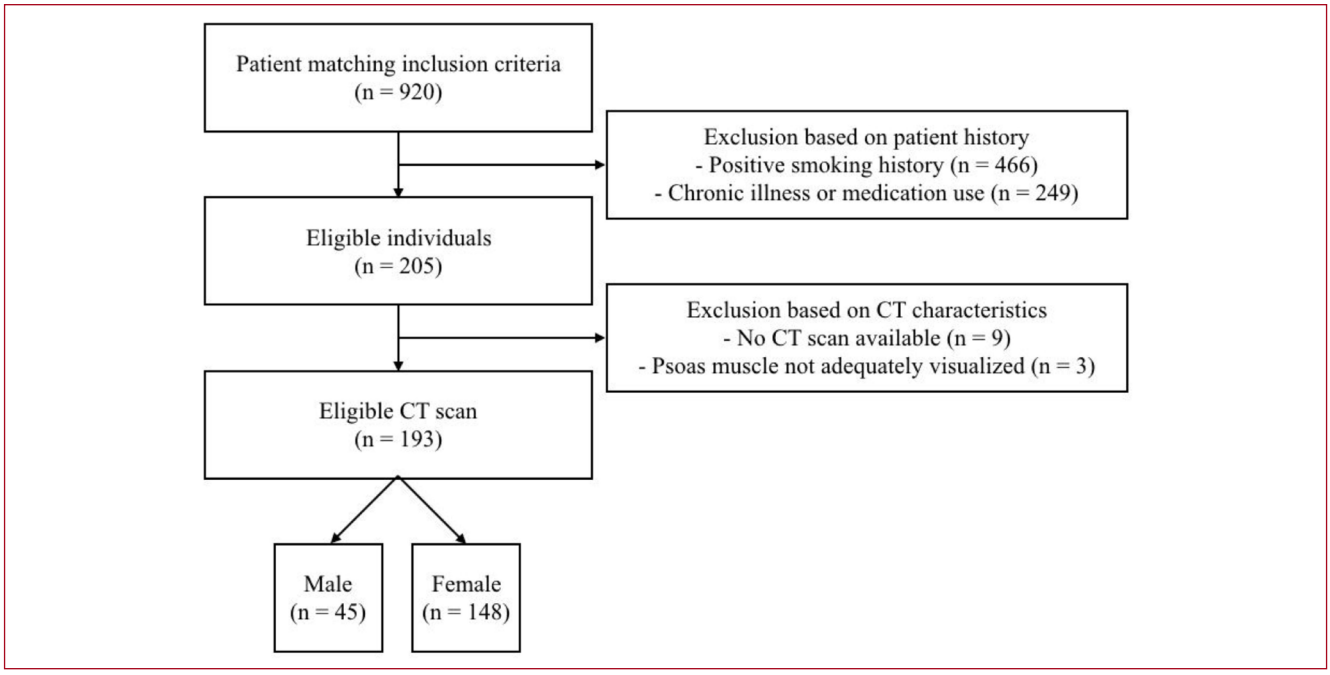


Figure 1. Study flowchart demonstrating the selection of eligible CT scans for muscle analysis. Inclusion search criteria consisted of alive, non-pregnant patients age 19-40 without diagnosis of hypertension or diabetes mellitus with diagnostic CT scan over study period July 2015-June 2018.

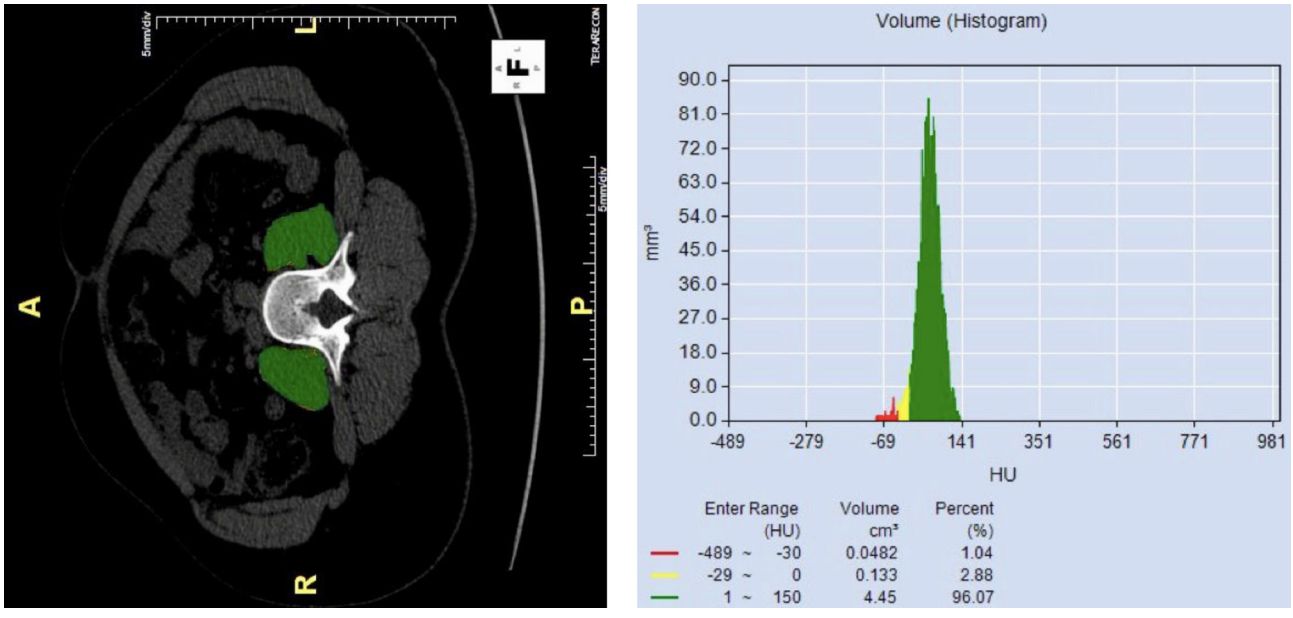
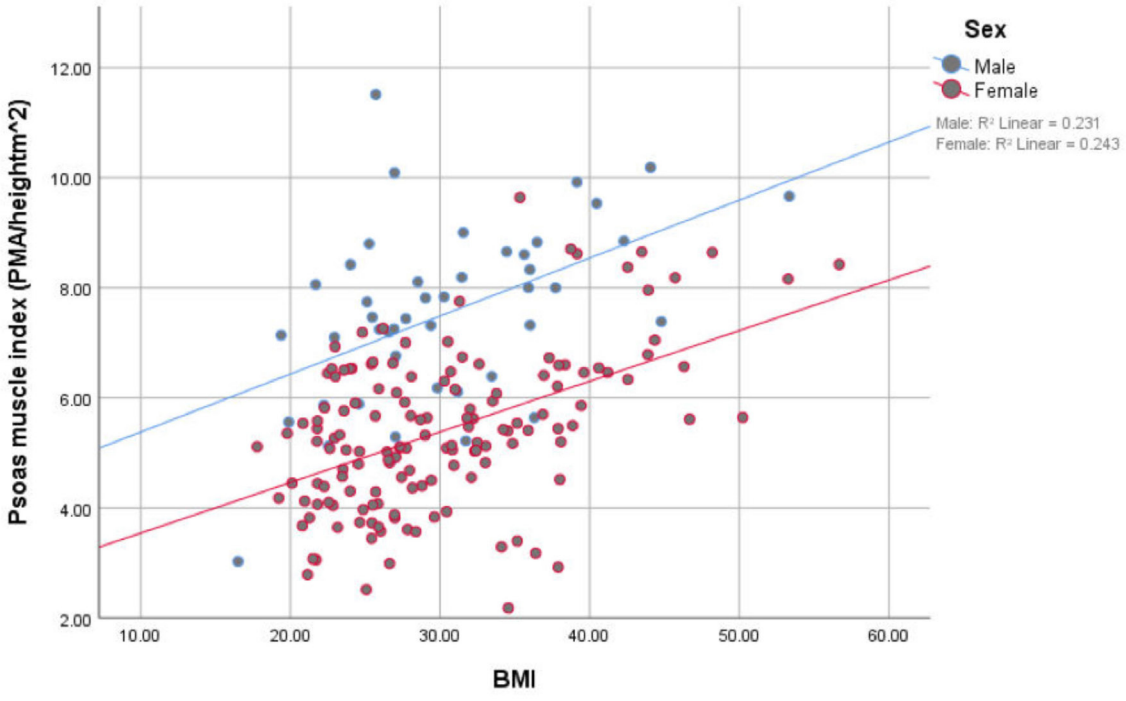


Figure 2. Representative picture of a single axial CT slice at the third lumbar vertebra for analysis of psoas muscle. Tracing followed by application of the color histogram tool automatically delineates the presence of skeletal muscle and adipose tissue. The psoas muscles bilaterally have a filter placed over them which colors muscle tissue green and adipose tissue red. Grey tissue falls within the HU range for muscle, but has not been covered with the filter. The volume histogram results are placed below the CT slice.



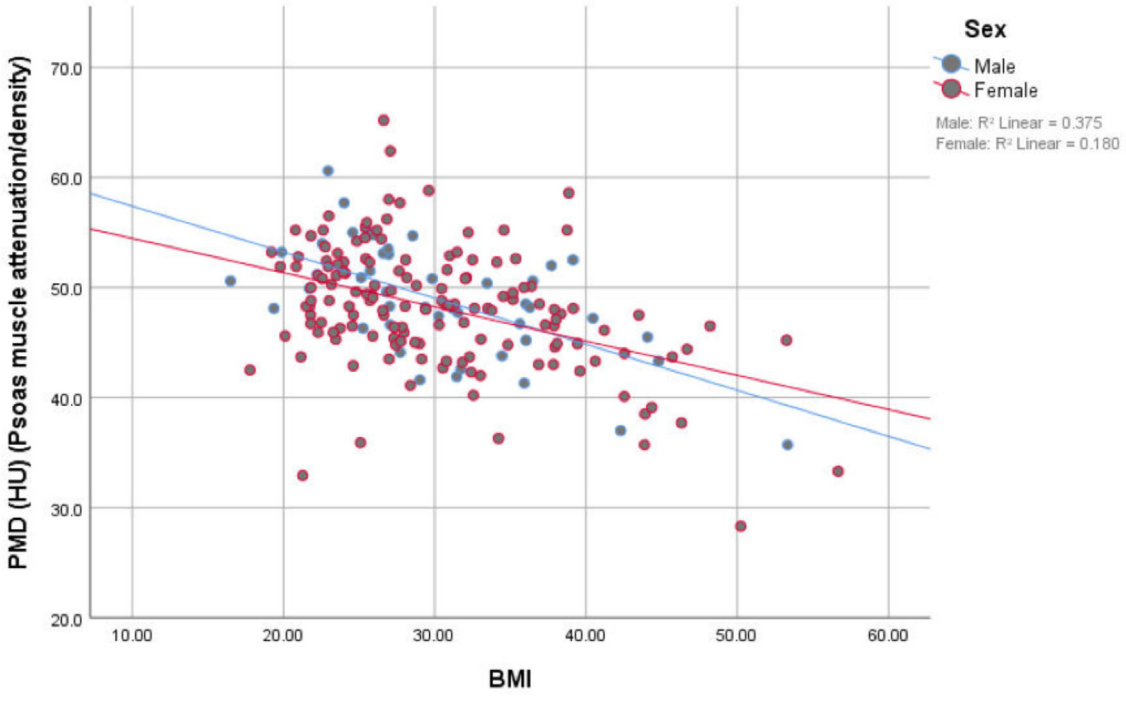


Figure 3. Scatter plots of multivariate analysis of age, sex, BMI, and muscle metrics. Linear associations between gender, age and BMI for Psoas muscle parameters (muscle area, psoas muscle index and psoas muscle attenuation). All associations were significant (p<0.001).

steroids, use of oral steroids, thyroid medications, weight loss medications, stimulants, antipsychotics and hormonal therapy. Recent trauma, hospitalizations and a postoperative or postpartum state at the time of the scan were additional exclusions. A past history of bowel surgery, spinal surgery or bariatric surgery were regarded as further exclusions. Oral birth control was not considered an exclusion, though long-acting hormonal therapy in females or males was regarded as an exclusion. The use of episodic medications or over-the-counter medications were not considered an exclusion. Non-obstructing kidney stones were not considered an exclusion. Demographic data collected included age, height and weight on the date of the scan and self-reported ethnicity and race. Ethnicity and race were limited to pre-set options in the hospital's EHR system. Body mass index was calculated as kilograms (kg)/meters (m)^2. The World Health Organization categories for overweight and obesity were used[31].

CT Scan selection

All CT scans done at the university medical center within the city were selected. All CT scanners had been regularly calibrated according to manufacturer instructions to ensure consistency of measurements. CT scanners included GE Revolution-256 Slice, GE VCT 64 Slice, GE Lightspeed Pro 16 Slice, and Siemen's 64 slice Somatom Definition. Images were either 2.5 or 3 mm thick. See Figure 1 for details on subject accrual.

Radiological technique

To standardize measurement, all cross-sectional measurements and measurements of the psoas muscle were taken at the third lumbar vertebra (L3) in a slice with both transverse processes visible. We assessed psoas muscle metrics including PMA, the bilateral surface area of the psoas muscle cross-section, PMI, the PMA divided by the participants height, and PMD, the mean muscle attenuation of the cross-section in Hounsfield units (HU)[17,18]. Measurements were confirmed using tissue-specific HU ranges of -29 to +150 for skeletal muscle and -190 to -30 for adipose tissue[32,33]. Measurement was performed by one investigator using Aquarius iNtuition software version 4.4.12 (Figure 2). To minimize anatomic differences, measurements were performed bilaterally via tracing of the circumference of the psoas muscle instead of using simple X-Y measurements. All scans were measured in a light-controlled radiological reading room.

Operator training and correlation

Investigator training was performed in accordance with the step-by-step guidelines for body composition analysis of a single cross-sectional CT image for skeletal muscle assessment as outlined by the NIH, under the supervision of a board-certified radiologist[12]. Methods were modified to fit a different picture archiving and communication software (PACS), though essential framework of the process with location, extraction, and evaluation of single slice images remained the same.

Inter-reader and Intra-reader reproducibility were assessed prior to the start of determining muscle measurements, and again 14 days later once half the images were analyzed, to ensure reliability. Intra-reader reproducibility was assessed by measuring the same axial slice on three separate occasions and assessing deviation. Inter-reader reproducibility was assessed by comparing the investigator's measurements with those of a board-certified radiologist for five distinct images at each assessment[34]. Audits were performed before beginning measurement and at two separate points during the course of measurement to ensure reliability.

Statistical methods

Data analyses were conducted using SPSS v25.0. Descriptive statistics, including means, standard deviations and percentiles were calculated for men and women. Differences between men and women were calculated using independent measures t-tests. Pearson's correlation coefficients assessed the relationships between BMI and psoas muscle metrics (psoas muscle index and psoas muscle density).

Results

Baseline Characteristics: The cohort of eligible study subjects (n=193) with eligible scans consisted of 45 males (23.3%) and 148 females (76.7%). The cohort was mainly Caucasian (76%). The selected age range was skewed to a slightly older population with mean age of 29.2 years (SD=5.9). The average BMI for our sample was 30.2 (SD=7.5) with 73.4% of our sample categorized as of overweight or obese (Table 1).

CT Scans: Indications for performing the selected CT scans were primarily related to kidney stones (59.1%) and abdominal pain not otherwise specified (32.1%). All other indications made up the remaining 8.8% of CT scans.

Muscle Indices: We calculated sex specific psoas muscle metrics (Tables 2 and 3). The average psoas muscle area (PMA) of our sample was 16.66 cm^2 (SD=6.1), or an average of 24.3 cm^2 (SD=5.8) in males and 14.5 cm^2 (SD=4.0) in females. When stratified for height, the average PMI was 5.90 cm^2/m^2 (SD=1.8) for the entire group with averages of 7.53 cm^2/m^2 (SD=1.7) for men and 5.5 cm^2/m^2 (SD=1.5) for women. Psoas muscle density (PMD), the average attenuation across the muscle slice, was 48.3 HU (SD=5.4) with averages of 48.85 HU (SD=5.1) for males and 48.18 HU (SD=5.5) for women.

For women, age was not significantly correlated with PMI (r=-0.105, p=0.206), but was significantly negatively correlated with PMD (r=-0.186, p=0.024) (Table 2). Conversely, for men, age was significantly negatively correlated with PMI (r=-0.337, p=0.024), but not PMD (r=0.010, p=0.950). BMI was significantly correlated with

	Males (n=45)	Females (n=148)	All Subjects (n=193)
Mean Age in years (SD)	31.1 (6.1)	28.6 (5.8)	29.2 (5.9)
Ethnicity/race percentage (frequency)			
Caucasian	71.1	77.6	76
African American	13.3	10.2	10.9
Latino and others	15.6	12.3	12.9
Mean Anthropometric measurements (SD)			
Height (cm)	179.2 (6.7)	163.0 (8.0)	166.8 (10.3)
Weight (kg)	98.3 (28.1)	80.2 (21.1)	84.4 (24.1)
BMI (kg/m^2)	30.4 (7.5)	30.2 (7.6)	30.2 (7.5)
BMI categories percentage (frequency)			
Underweight (less than 18.5 kg/m^2)	2.2% (1)	0.7% (1)	1.0% (2)
Normal weight (18.5-24.99 kg/m^2)	17.8% (8)	27.7% (41)	25.5% (49)
Overweight (25-29.9 kg/m^2)	35.6% (16)	27.0% (40)	29.2% (56)
Obese Class 1 (30-34.9 kg/m^2)	15.6% (7)	20.3% (30)	19.3% (37)
Class 2 (35-39.9 kg/m^2)	17.8% (8)	13.5% (20)	14.6% (28)
Class 3 (40 kg/m^2 and above)	11.1% (5)	10.1% (15)	10.4% (20)

† Characteristics are described using numbers (percentages) or mean ± standard deviation. Adult BMI categories derived from CDC definition (https://www.cdc.gov/obesity/adult/defining.html). BMI Body mass index.

Table 1. Demographic, anthropologic, and metabolic characteristics of study population.

		Age		BMI	
		r	p-value	r	p-value
Psoas muscle density (PMD) (HU)	Female	-0.186	0.024	-0.425	<0.001
	Male	0.010	0.950	-0.613	<0.001
Psoas muscle index (PMI) (cm^2/m^2)	Female	-0.105	0.206	0.446	<0.001
	Male	-0.337	0.024	0.481	<0.001

PMI Psoas muscle index, PMD Psoas muscle density, BMI Body mass index, HU Hounsfield unit.

Table 2. Correlations between psoas muscle metrics and age, BMI by sex.

PMI and PMD for both men and women. BMI was found to be directly correlated with increasing lean muscle mass and indirectly correlated with muscle density (Figure 3).

Table 3 presents the percentiles for PMI and PMD broken down by BMI and sex that can be used as a normal reference sample for a healthy, predominately Caucasian, sample of adults aged 19-40 in the Midwestern United States. PMA and PMI values did not differ significantly across device manufacturers (Siemens and GE); however, a significant difference in PMD between manufacturers was noted (p<0.001). When comparing both intra-reader reliability between different tracings done by the investigator and inter-reader reliability between the investigator and a board-certified radiologist, the intraclass correlation coefficients (ICC) were greater than 0.96 for all comparisons with p-values <0.001.

Discussion

Psoas muscle metrics for sex, age and BMI-specific values are presented from our study of a young, healthy, and predominately Caucasian population in the Midwestern United States. To the best of our knowledge, this is the first report that specifically includes psoas muscle indices and novel psoas indices of muscle density to illustrate intramuscular fat deposition. Our study supports those that

Psoas Muscle index (cm^2/m^2)							
Males	**All BMI (kg/m^2)**	**<18.5**	**18.5- 24.9**	**25.0- 29.0**	**30.0-34.9**	**35.0-39.9**	**>40**
p5	5.0	3.0	5.1	4.9	5.2	5.6	7.4
p10	5.3	3.0	5.1	5.2	5.2	5.6	7.4
p25	6.3	3.0	5.6	6.9	6.1	7.5	8.1
p50	7.5	3.0	6.5	7.4	7.8	8.2	9.5
p75	8.6	3.0	7.8	8.0	8.7	8.8	9.9
p90	9.8	3.0		10.5			
p95	10.2	3.0					
Females	**All BMI (kg/m^2)**	**<18.5**	**18.5- 24.9**	**25.0- 29.0**	**30.0-34.9**	**35.0-39.9**	**>40**
p5	3.1	5.1	3.1	3.0	2.8	2.9	5.6
p10	3.6	5.1	3.7	3.6	4.0	3.2	5.6
p25	4.4	5.1	4.1	3.9	5.0	5.3	6.5
p50	5.4	5.1	5.0	4.8	5.3	5.8	7.0
p75	6.5	5.1	5.8	5.9	6.1	6.6	8.4
p90	7.2	5.1	6.5	6.7	6.7	8.7	8.6
p95	8.4	5.1	6.9	7.3	7.4	9.6	
Psoas muscle density (HU)							
Males	**All BMI (kg/m^2)**	**<18.5**	**18.5- 24.9**	**25.0- 29.0**	**30.0-34.9**	**35.0-39.9**	**>40**
p5	38.3		48.1	41.6	41.9	41.3	35.7
p10	41.8	50.6	48.1	43.4	41.9	41.3	35.7
p25	45.9	50.6	50.2	47.0	42.6	45.6	36.4
p50	48.5	50.6	53.6	50.9	47.4	48.4	43.3
p75	52.8	50.6	57.0	53.4	48.1	51.7	46.4
p90	54.9	50.6		55.0			
p95	57.0	50.6					
Females	**All BMI (kg/m^2)**	**<18.5**	**18.5- 24.9**	**25.0- 29.0**	**30.0-34.9**	**35.0-39.9**	**>40**
p5	38.1	42.5	43.0	41.2	38.4	42.4	28.3
p10	42.4	42.5	45.4	43.6	42.0	43.0	31.3
p25	45.0	42.5	46.8	45.7	43.6	44.9	37.7
p50	48.3	42.5	50.3	49.4	48.3	47.8	43.3
p75	51.9	42.5	52.4	54.2	51.1	49.9	45.2
p90	55.2	42.5	54.6	57.6	53.2	54.9	46.9
p95	56.4	42.5	55.2	62.2	55.1	58.4	

Table 3. Mean gender specific psoas muscle parameters (PMA, PMI, PMD) by BMI.

show that age and sex are well known predictors of muscle decline; we found that advancing age was associated with diminished muscle metrics for most parameters and BMI was found to be related to psoas muscle area and density.

Most reports indicate the occurrence of a paradoxical muscle loss in patients with obesity. Longitudinal population studies from Korea in an older cohort showed body weight to be negatively associated with muscle mass[36]. In contrast, in the younger population included in our study, we observed a positive correlation of muscle area with BMI.

Importantly, we noted an inverse relationship between BMI and psoas muscle density, indicating the preserved muscle mass may be falsely elevated as a result of fatty infiltration into muscle. While the muscle area has increased,

the less dense composition indicates a lower quality and less useful muscle mass. We presume that lean muscle mass is relatively preserved in our young cohort, and that in the subjects with obesity, similar decline may eventually become evident as they age. The concomitant use of the PMD may provide greater accuracy by allowing for characterization of muscle in addition to quantification. If muscle quality declines precede pathologic loss, our methods would allow for detection of changes prior to other measurements. Intramuscular fat is seldom assessed and is said to have increasing significance in disease processes[38–40].

There are well-reported ethnic differences in body composition[37] which could offer another explanation as to why our findings in a predominantly Caucasian cohort, as is typically seen in the Midwestern US, differ from a population from East Asia[36].

The normal percentile values we reported in Table 3 can be used as reference, particularly for a predominately Caucasian, Midwestern US population presenting for medical care. Such data allows for comparison studies and diagnostic cutoffs to be established for gender, age and weight. As additional data are obtained, such as those specific to ethnicity and particular diseases, the eventual translation of muscle metrics into the clinical profile of a patient has the potential to inform individualized medical management. Our technique shows promise in the clinical context because it requires minimal training and resources and uses standardized methodology which can be easily incorporated at other medical centers. CT scan body composition analysis has been simplified and largely automated by the use of dedicated software, simultaneously reducing costs and increasing the accessibility and reproducibility of muscle metric assessments[45].

A major strength of this study was our stringent inclusion criteria for selecting a healthy representative cohort, limiting comorbidities, to reduce the number of variables potentially affecting the attenuation of a CT scan. We ensured high accuracy of our scans by selecting high-quality images without contrast. While use of both contrast and non-contrast CT scans have been reported in many studies focusing solely on muscle mass, since we are reporting novel muscle density results as well, we could not risk potential interference from the contrast medium on the results. One factor we could not control was the potential impact of device manufacturer on muscle density (PMD) as measured in HU. CT scanners, even when regularly calibrated, vary between manufacturers[41,42]. While we found a significant difference on PMD when comparing devices from different manufacturers, other potential factors affecting muscle attenuation include hydration, body fat content, exercise training levels, and population differences[43]. These differences can be potentially minimized in future studies by using scanners from a single manufacturer or using a calibration phantom[42].

Limitations in any retrospective study are inherent due to missing or incorrect data or other factors. Though we tracked self-reported race, this category was limited by the pre-set options in the hospital medical record system. Additionally, specific information on the ethnicity of our patients was unavailable at the time of data collection. The county in which the study took place is 12.9% Hispanic, which should approximate the ethnic distribution of our sample[44]. One limitation to our study is the preponderance of females in our cohort. However, other reports from free-living community settings report similar findings. This difference may be attributed to higher health care seeking rates in women[35,36]. We did not find this to be a confounding factor in our results. Another limitation is that our sample size may have been constrained due to the possibility that our list of exclusions was too restrictive. Additionally, our utilization of only non-contrast CT scans may have an unknown selection bias. Finally, we could not assess for physical activity, level of fitness, or nutritional intake of the study population.

In future clinical visits, a quick tracing of the psoas muscle from an incidental CT scan may add depth to a consult on weakness with real-time analysis and better prognostic information than otherwise available[34]. Sarcopenia is targetable and reversible, though mostly occult, hence provision of body composition metrics to clinicians can likely lead to intervention in a more accurate and timely fashion. The eventual aim is to be able to decrease mortality and improve quality of life across a spectrum of disease states.

Conclusion

CT derived muscle metrics are poised to become a ubiquitous tool in the future, yet normal values of psoas muscle indices for a healthy young US population have not been established[3]. We provide sex specific psoas muscle indices for a cohort of healthy young adults from a Midwestern cohort, with stratification for age, sex, and BMI.

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