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Original Article

Psoas Major Cross-sectional Area: A Potential Marker of Cardiorespiratory Fitness

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Abstract

Background and Aim: Cardiorespiratory fitness is an important marker for overall health that significantly correlates with obesity-associated morbidities and mortality. Maximal oxygen uptake (VO_{2max}) recorded during an incremental exercise test is the gold standard assessment for aerobic fitness. However, its cost, chronic illness, and frailty often preclude its application. The cross-sectional area (CSA) of the abdominal psoas major muscle is a predictor of sarcopenia and surgery outcomes and represents a promising biomarker for cardiorespiratory health. Therefore, in the present study, we have planned to assess the relationship between psoas major CSA, anthropometry, and body composition in a UK-based cohort of 210 men and women. **Methods:** Body mass (kg), height (cm), waist circumference (cm), VO_{2max}, and blood pressure were measured in each participant. The CSA of psoas major, rectus abdominus, and another abdominal muscle of the core muscle group were assessed. **Results:** Following adjustment for height, psoas major CSA was found to be a significant predictor of percentage body fat ($P = 0.02$) in men, and body mass index (BMI) in both men ($P = 0.015$) and women ($P = 0.004$). We found psoas major CSA correlated more strongly with VO_{2max} ($r = 0.74$, $P < 0.01$) than any other study outcome, including age and BMI. **Conclusion:** Psoas major muscle CSA represents an accurate, reproducible, and time-efficient surrogate for cardiorespiratory fitness and body composition.

Keywords: Cardiorespiratory fitness, magnetic resonance imaging, maximal oxygen uptake, psoas muscle

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Introduction

Physical inactivity significantly contributes to both morbidity and mortality, with public health organizations now increasingly promoting habitual exercise to reduce the negative impact of a sedentary lifestyle.[1,2] Improvements in cardiorespiratory fitness are a key target for intervention, with maximal oxygen uptake (VO_{2max}) recorded during an incremental exercise test to exhaustion, being considered the gold standard.[3,4] Cardiorespiratory fitness is inversely related to fat mass,[3] type 2 diabetes prevalence,[5] and a more reliable predictor of mortality than other established markers, such as blood pressure or circulating cholesterol.[6] However, the time commitment and cost of performing these tests often make them impractical, and chronic illness or frailty in elderly patients precludes their application. Consequently, there is a need for accurate and reproducible biomarkers for use as surrogates of cardiorespiratory fitness.

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Morphometric analysis of core muscle cross-sectional area (CSA) is emerging as a strong indicator of health outcomes,[7] with an increase in muscle fiber CSA as the main functional adaptation arising from aerobic and strength training.[8] The psoas major is a large muscle of the abdomen, forming part of the core muscle group, assisting lateral rotation and abduction of the hip joint.[9] Psoas major CSA has been used in a number of studies to predict the total body lean muscle mass,[10] sarcopenia,[11] and surgical outcomes in elderly patients.[12,13] It therefore represents a potential marker for cardiorespiratory fitness.

In the present study, we would like to characterize how the CSA of psoas major and the rectus abdominus (RA), another

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abdominal muscle of the core muscle group, vary with age, gender, and BMI in a cross-sectional population. Second, in a subset of our cohort, we have assessed the relationship between these muscles CSA and VO_{2max} to gauge their potential as a surrogate marker for overall physical health.

Materials and Methods

Ethical approval

Written informed consent was acquired from all volunteers. Ethical approval for this study was obtained from the Brent National Research Ethics Committee (Rec: 12/LO/0139). All studies were carried out in accordance with the Declaration of Helsinki. In total, 210 participants were recruited through advertisements in newspapers, websites, academic newsletters, and inviting male and female volunteers of Caucasian ethnicity from the general public. Participants presented with no history of chronic disease or excess alcohol intake were included in the study. Individuals on prescribed medication and pregnant women were excluded from the study.

Anthropometry, blood pressure, and clinical biochemistry

Body mass (kg), height (cm), and waist circumference (cm) were measured in each participant by a single experienced observer. Fasting glucose, total cholesterol, triglycerides, high-density lipoprotein, low-density lipoprotein, and insulin were measured by standard methods by the Department of Chemical Pathology, Imperial College Healthcare National Health Service Trust. Blood pressure of the participants was measured by trained clinician using an automatic sphygmomanometer after 5 min of rest in supine position.

Scanning

Individuals underwent magnetic resonance imaging (MRI) at 1.5T (Archiva, Philips Medical Systems, The Netherlands) following an overnight fast. Participants were in prone position, and T1-weighted axial images of the whole body were obtained as described previously.[14] During the same scanning session, ^{1}H MR spectra were also acquired at 1.5T. Using a surface coil, intrahepatocellular lipid (IHCL) was measured relative to liver water content.[15]

Psoas major and rectus abdominus

Using the open source image processing program Image-J (NIH, USA), the CSA of the psoas major was manually isolated at lumbar point L3/L4. The CSA of the rectus abdominis (RA), which can also be clearly observed within the same axial slice, was measured from the same MRI images to provide a comparison core muscle. The CSA values for each muscle group in this study correspond to the sum of the CSA of the right- and left-hand sides [Supplementary Figure 1]. Due to the strong correlation between psoas major muscle and height, values are also presented as CSA/height^2 (mm^2/m^2).[16]

Reproducibility

To test the reproducibility of the manual analysis of psoas major and RA CSA, two separate exercises were undertaken. In test 1, left and right muscle CSA [Supplementary Figure 1] were assessed three times in a row by the same observer; psoas: (Average [standard deviation [SD]) 4165.1 ± 24.37 mm^2, coefficient of variation (CoV): 0.59%; RA: 1826.0 ± 9.2 mm^2, and CoV: 0.50%. In test 2, the same axial slice was measured on three separate occasions, at 1 week intervals; average (SD): 4117.3 ± 61.92 mm^2 and CoV: 1.5%. In test 2, the analysis was repeated three times on a single, randomly chosen image, 1 week apart by the same observer; psoas CoV: 2.9% and RA: 3.7%.

VO_{2max} assessment

An incremental cycling test to exhaustion[4] was carried out on the same study day as the MRI scan to obtain VO_{2max} in a subset of the cohort (99 individuals [67 male, 32 female]).

Statistical analysis

Student's *t*-test and Spearman's rank correlations were performed on variables; psoas major CSA, RA CSA, and VO_{2max}. Linear regression was performed in GraphPad Prism version 6.0 (GraphPad Software, USA). IHCL values were log transformed after adding + 1 to their values due to the nonnormally distributed nature of the outcome.[14] Correlation was performed in SPSS 23 (IBM SPSS Statistics for Windows, USA) and linear regression in GraphPad Prism. $P < 0.05$ was considered significant. All data were presented as mean ± SD.

Results

A total of 210 participants (97F, 113M) took part in the initial study to characterize psoas major and RA muscles, both raw

Table 1: Characteristics of baseline cohort *n* = 210 (113 male, 97 female)

	Mean±SD	Range
Age (year)	43.8±14.5	18-67
Weight (kg)	79.8±18.1	40.7-146.6
Height (m)	1.7±0.1	1.5-2.0
BMI (kg/h^2)	26.6±5.1	15.5-47.5
Waist (cm)	90.2±15.7	56.5-131
Hip (cm)	103.6±9.5	76-136
WHR	0.87±0.1	0.67-1.09
Psoas major CSA (mm^2/m^2)	2857±1051	718-7458
Psoas major CSA/height^2	942±293	231-2312
RA CSA (mm^2/m^2)	1333±515	554-3217
RA/height^2	436141	198-998
S-IMCL	13.4±7	2.28-50.4
T-IMCL	6.4±3.5	0.25-30.5
IHCL	3.7±9.8	0.0-108.7
Total fat (kg)	24.3±11.1	5.4-67.0
Subcutaneous (kg)	19.3±9.2	3.79-57.3
Internal (kg)	5.0±2.8	0.88-14.7
Subcutaneous abdominal (kg)	5.5±3.2	0.65-18.2
Subcutaneous peripheral (kg)	13.8±6.1	3.14-39.7
Visceral (kg)	2.7±1.9	0.31-10.4
Nonvisceral internal (kg)	2.3±1.0	0.53-6.2

Data presented as mean±SD. WHR: Waist to hip ratio, BMI: Body mass index, CSA: Cross-sectional area, RA: Rectus abdominis, S-IMCL: Soleus intramyocellular lipid, T-IMCL: Tibialis intramyocellular lipid, IHCL: Intrahepatocellular lipid, SD: Standard deviation

and adjusted for height, are summarized in Table 1. Average psoas CSA/height^2 and RA CSA/height^2 measurements for the entire cohort were 942 + 93 and 436 ± 141, respectively. Women presented with significantly smaller psoas and RA when compared to men (psoas CSA/height^2: female 741 + 167 mm^2/m^2, male 1114 + 266 mm^2/h^2, $P < 0.001$; RA CSA/height^2: female 324 ± 73 mm^2/h^2, male 491 ± 134 mm^2/h^2, $P < 0.001$).

Figure 1 shows how muscle CSA, adjusted for height, varied by gender, age, BMI, and percentage body fat. Linear regression analysis revealed a significant inverse relationship between psoas CSA/height^2 and age in men [$r = 0.13$; $P = 0.016$, Figure 1a] with no effect in women [Figure 1b]. Both psoas major CSA/height^2 ($r = 0.28$; $P = 0.004$) and RA CSA/height^2 ($r = 0.46$; $P < 0.001$) were significant predictors of BMI in women [Figure 1d], while only psoas major CSA/height^2 predicted BMI in men ($r = 0.22$, $P = 0.015$). Lastly, psoas major CSA/height^2 was a significant inverse predictor of body fat percentage in men [$r = 0.22$; $P = 0.02$, Figure 1e]. Examination of the relationship between psoas and RA with metabolically adverse fat depots, visceral fat and IHCL, can be found in Figure 2. Psoas major CSA/height^2 inversely predicted visceral fat in men [$r = 0.20$; $P = 0.02$, Figure 2a], while RA CSA/height^2 was a significant predictor of IHCL in women [$r = 0.22$; $P = 0.02$, Figure 2b].

A comparison of how psoas major and RA muscles (after adjustment for height) correlate with study outcomes is shown in Supplementary Figure 2. Both psoas major CSA/height^2 and RA/height^2 were inversely correlated with age ($r = -0.49$, $P < 0.01$, $r = -0.50$, $P < 0.01$). RA/height^2 was significantly associated with visceral ($r = 0.28$, $P < 0.01$) and nonvisceral adipose tissue ($r = 0.20$, $P < 0.05$) with no correlation observed with psoas major CSA/height^2 (P = NS).

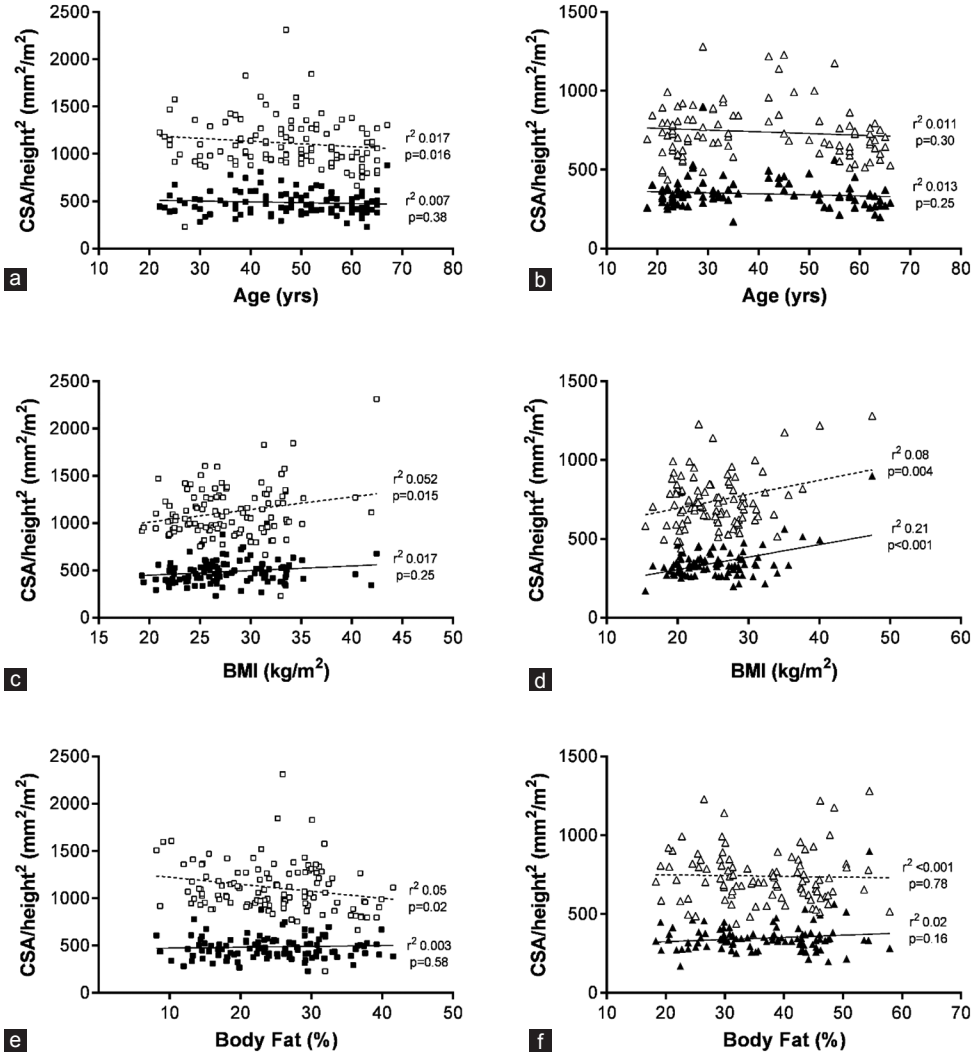

Figure 1: Gender-specific distribution of psoas and rectus abdominus muscle cross-sectional area/height^2 with age, body mass index, and percentage body fat. Cross-sectional area adjusted for height (cross-sectional area/height^2) of psoas major (white square/circle) and rectus abdominus (black square/circle) muscles in men (a, c and e) and women (b, d, and f) by age (a and b), body mass index (c and d), and percentage body fat (e and f). Linear regression performed in GraphPad Prism with corresponding r^2 and P values. □: Male psoas; Δ: Female psoas; ■: Male rectus abdominus; ▲: Female rectus abdominus

Further investigation in a smaller, older subset of the cohort for which VO_{2max} was available (n = 105 (72M), age 54.5 ± 8.5 years) was carried out to assess the validity of psoas major and RA muscle CSA as a marker for cardiorespiratory fitness. Baseline characteristics for this cohort are shown in Supplementary Figure 3. Average VO_{2max} was 2523 ± 1091 ml/min, with female VO_{2max} lower (1520 ± 332 ml/min) than male (3002 ± 998 ml/min). After correction for weight, male VO_{2max} was 32.2 ± 12.1 ml/kg/min, while female was 19.9 ± 4.3 ml/kg/min.

Correlation analysis between VO_{2max} (adjusted for weight) and study outcomes is shown in Table 2. Psoas major muscle CSA/height^2 (mm^2/m^2) correlated strongly with VO_{2max} (ml/kg/min) (r = 0.56, P < 0.01), with no association observed with RA CSA/height^2 (r = 0.17, P = NS). Both age (r=-0.64) and height (r = 0.49) correlated strongly with VO_{2max} to a similar degree of significance (P < 0.01). Gender-specific analysis revealed a significant correlation between psoas major CSA/height^2 and VO_{2max} (ml/kg/min) (r = 0.33, P < 0.01) in males. In female volunteers, VO_{2max} (ml/kg/min) correlated strongly with individual adipose compartments but no associations were observed with anthropometric or core muscle group measurements [Table 2].

Gender-specific distribution of psoas major and RA CSA/height^2 with VO_{2max} (ml/kg/min) is shown in Figure 3. Linear regression revealed psoas major CSA/height^2 which were significant predictors of VO_{2max} in male participants [P < 0.001, Figure 3a], with no effect in women [Figure 3b]. RA muscle was not found to be a significant predictor of VO_{2max} in either men or women [Figure 3].

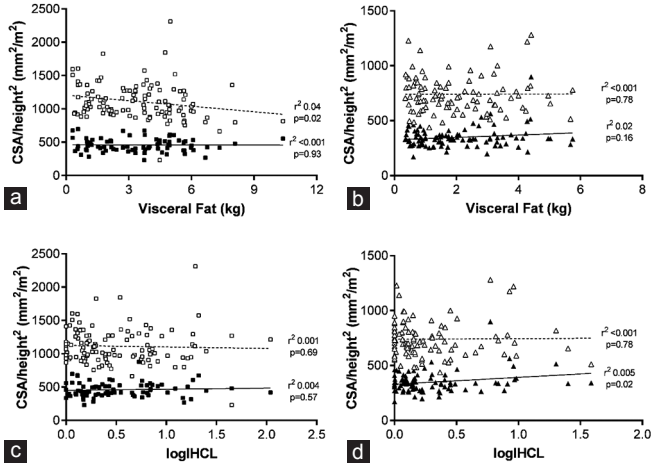

Figure 2: Gender-specific distribution of psoas major and rectus abdominus muscle cross-sectional area/height^2 with visceral fat and intrahepatocellular lipid. Cross-sectional area adjusted for height (cross-sectional area/height^2) of psoas major (white square/circle) and rectus abdominus (black square/circle) muscles in men (a and c) and women (b and d) by visceral fat (kg) (a and b) and log intrahepatocellular lipid (c and d). Linear regression performed in GraphPad Prism with corresponding r^2 and P values. □: Male psoas; Δ: Female psoas; ■: Male rectus abdominus; ▲: Female rectus abdominus

Discussion

In the present study, we characterize how the CSA of psoas major and RA muscles varies with age, gender, and BMI in a cross-sectional population. The CSA of the psoas major strongly correlated with and was a significant predictor of VO_{2max} in a male subset of our cohort, with no such relationship observed with RA.

Physical inactivity is a leading cause of most chronic illness and practical methods to determine fitness levels are needed to enable effective assessment of lifestyle interventions and public health planning.[17,18] The use of MRI and computerized tomography (CT) scans to measure the content and distribution of body fat is increasingly common in both research and clinical fields, with cross-sectional abdominal imaging a common procedure in a diagnostic setting. Postprocessing of abdominal region scans enables an in-depth investigation of tissue morphology, including the CSA of different muscles.

Muscle size represents a quantitative index, reflecting general health and intervention risk.[19] While obtaining whole-body images can be time-consuming and expensive, studies have shown that the CSA of abdominal skeletal muscle provides a reliable surrogate of whole body muscle mass.[10] Within this region lies the psoas major muscle, a component of the core muscle group and a surrogate marker for sarcopenia and surgical outcomes.[9,12,20] The RA muscle, often referred to as the abdominals, is another component of the core muscle group that lies within the L4 region and was included in our analysis as a comparator. The psoas major is easily identified on axial images in both MRI and CT scan, and analysis of muscle CSA can be easily translated into any research institute where cross-sectional imaging of the abdominal region is available using this simple and straightforward method.

Our data indicate psoas major CSA predicts VO_{2max}, albeit in men only, with no such effect observed with RA. Correlation analyses of RA and psoas major CSA adjusted for height revealed comparable degrees of association for the majority of study outcomes. There was however a significant inverse correlation between psoas major CSA and age, a

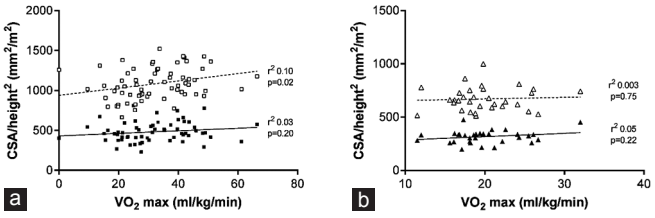

Figure 3: Gender-specific distribution of psoas major and rectus abdominus muscle cross-sectional area/height^2 with maximal oxygen uptake (ml/kg/min). Cross-sectional area adjusted for height (cross-sectional area/height^2) of psoas major (white square/circle) and rectus abdominus (black square/circle) muscles in (a) men and (b) women. Linear regression performed in GraphPad Prism with corresponding r^2 and P values. □: Male psoas; Δ: Female psoas; ■: Male rectus abdominus; ▲: Female rectus abdominus

Table 2: Correlation analysis of maximal oxygen uptake with study outcomes

VO_{2max} (ml/kg/min)	All	Male	Female
Age (year)	**−0.64****	**−0.61****	−0.08
Weight (kg)	0.02	**−0.32****	−0.30
Height (m)	**0.49****	0.21	−0.11
BMI (kg/h^2)	**−0.35****	**−0.47****	−0.33
Waist (cm)	−0.19	**−0.62****	−0.01
Hip (cm)	−0.19	**−0.43****	−0.05
WHR	−0.10	**−0.65****	0.10
Psoas major CSA/height^2	**0.56****	**0.33****	0.06
RA/height^2	0.17	−0.15	0.22
SBP	−0.10	−0.15	−0.23
DBP	−0.11	−0.30	−0.20
Glucose (mmol./l)	−0.06	−0.14	0.06
Insulin (mU/l)	0.04	−0.02	−0.06
Cholesterol (mmol/l)	0.10	0.35*	0.04
Triglycerides (mmol/l)	0.17	0.08	−0.04
HDL cholesterol (mmol/l)	−0.10	0.21	0.19
LDL cholesterol (mmol/l)	−0.03	0.12	−0.02
Cholesterol: LDL ratio	0.13	0.03	−0.18
S-IMCL	−0.15	−0.19	−0.38*
T-IMCL	−0.15	−0.17	0.03
IHCL	−0.15	−0.24	−0.14
Total fat (kg)	**−0.63****	**−0.58****	−0.41*
Subcutaneous (kg)	**−0.60****	**−0.49****	−0.43*
Internal (kg)	**−0.49****	**−0.71****	−0.26
Subcutaneous abdominal (kg)	**−0.55****	**−0.45****	−0.42*
Subcutaneous peripheral (kg)	**−0.62****	**−0.49****	−0.42*
Visceral (kg)	**−0.39****	**−0.66****	−0.26
Nonvisceral internal (kg)	**−0.57****	**−0.71****	−0.21

Correlation analysis of VO_{2max} (ml/kg/min) with anthropometric, metabolic, and body composition outcomes. Data shown are Pearson's coefficients; shaded boxes indicate a significant correlation, bold typeface indicates a higher degree of significance. *P<0.05, **P<0.01. SBP: Systolic blood pressure, DBP: Diastolic blood pressure, WHR: Waist to hip ratio, BMI: Body mass index, CSA: Cross-sectional area, RA: Rectus abdominis, LDL: Low-density lipoprotein, HDL: High-density lipoprotein, S-IMCL: Soleus intramyocellular lipid, T-IMCL: Tibialis intramyocellular lipid, IHCL: Intrahepatocellular lipid, VO_{2max}: Maximal oxygen uptake

relationship not observed with RA. In addition, while the psoas was negatively correlated with total, subcutaneous, and subcutaneous abdominal fat, RA also showed a positive correlation with metabolically adverse visceral and internal fat stores.[21] Cardiorespiratory fitness is known to be a significant predictor of fat mass and together these data indicate that of the two core muscles, the psoas major is the more viable marker for metabolic and cardiovascular health.

Ethnic differences exist regarding muscle mass distribution[22] and to avoid these potentially confounding effects, study recruitment was limited to Caucasians. Further research is therefore warranted to determine the influence of broader participant demographics on the positive associations between psoas major CSA, cardiorespiratory fitness, adiposity, and fat-free mass. As expected, the CSA of both psoas major and RA muscles was significantly smaller in women compared to men, necessitating gender-specific analysis. The inverse relationship observed between psoas and age in men was expected and reflects an established association.[22] However, in women, we failed to see a reduction in either psoas major or RA size as age increased, or indeed any correlation between VO_{2max} and other outcomes. Indeed, it is clear that the significant associations we did observe between VO_{2max} and study outcomes were driven by the relationship in men.

Several factors may have contributed to this; first, the number of women for which VO_{2max} data were available was considerably smaller (n = 33) compared to men (n = 72). Second, the range of VO_{2max} values was more limited in women (511–1175 ml/min) than men (663–2312 ml/min), perhaps reflecting the reduced levels of reported physical activity in women who participated; 24% reported "fit" (corresponding to >5 h exercise per week), compared to 42% of the men. Interventional studies which employ exercise and subsequently measure the effects on VO_{2max} and core muscle size will be required to eliminate the confounding effects of age and determine the efficacy of psoas as a marker of metabolic fitness.

Limitations of the study

Sample size in the present study was less.

Conclusion

Our findings indicate that psoas major CSA measured at L4 is strongly associated with cardiorespiratory fitness, adiposity, and fat-free mass. Hence, psoas major is a potential marker of cardiorespiratory fitness. Additional work in a larger, racially diverse population with a more expansive range of fitness levels will be required to confirm its utility.

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Conflicts of interest

There are no conflicts of interest.

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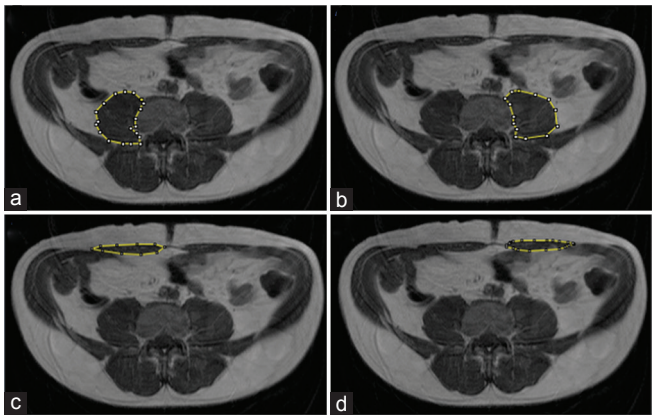

Supplementary Figure 1: Psoas and rectus abdominus coronal slices at position L4 used to identification and manually measure cross-sectional area of psoas major (a and b) and rectus abdominis (c and d) muscles using Image –J software

Supplementary Figure 2: Correlation analysis of psoas major and rectus abdominis muscle cross-sectional area adjusted for height

	Psoas/height^2	RA/height^2
Age (year)	−0.49**	−0.50**
Weight (kg)	0.48**	0.56**
Height (m)	0.51**	0.48**
BMI (kg/h^2)	0.25**	0.40**
Waist (cm)	0.24*	0.39**
Hip (cm)	0.09	0.17
WHR	0.28**	0.44**
SBP	0.03	−0.003
DBP	0.18	0.19
Glucose (mmol/l)	0.13	0.11
Insulin (mU/l)	0.13	0.03
Cholesterol (mmol/l)	−0.49**	−0.38**
Triglycerides (mmol/l)	−0.21	−0.35**
HDL cholesterol (mmol/l)	0.30*	0.17
LDL cholesterol (mmol/l)	0.02	0.07
Cholesterol: LDL ratio	0.18	0.10
S-IMCL	0.06	0.22*
T-IMCL	−0.04	0.12
IHCL	0.10	0.13
Total fat (kg)	−0.23*	−0.06
Subcutaneous (kg)	−0.33**	−0.20*
Internal (kg)	0.01	0.18
Subcutaneous abdominal (kg)	−0.22*	−0.06
Subcutaneous peripheral (kg)	−0.17	0.03
Visceral (kg)	0.14	0.28**
Nonvisceral internal (kg)	0.17	0.20*

Data shown are Pearson's coefficients; shaded boxes indicate a significant correlation. *P<0.05, **P<0.01. SBP: Systolic blood pressure, DBP: Diastolic blood pressure, WHR: Waist to hip ratio, BMI: Body mass index, RA: Rectus abdominis, LDL: Low-density lipoprotein, HDL: High-density lipoprotein, S-IMCL: Soleus intramyocellular lipid, T-IMCL: Tibialis intramyocellular lipid, IHCL: Intrahepatocellular lipid

Supplementary Figure 3: Baseline characteristics of cardiorespiratory assessment cohort (n=102)

	n=105 (72 male)	Range
Age (year)	54.5±8.5	35-66
Weight (kg)	88.2±16.8	58.6-146.6
Height (m)	1.74±0.1	1.51-1.95
BMI (kg/m^2)	29.1±4.0	19.4-42.4
Waist (cm)	99.5±12.7	71.6-131.0
Hip (cm)	107.9±8.4	88.5-136.0
WHR	0.92±0.08	0.67-1.09
Psoas CSA (mm^2)	3010±1115	1165.9-7458
Psoas CSA/height (m)^2	977±301	511-2312
RA CSA (mm^2)	1333±515	554-3217
RA/height (m)^2	436±141	198-997
VO_{2max} (ml/min)	2523±1091	930-5402
VO_{2max} (ml/kg/min)	28.2±11.8	0-67
SBP (mmHg)	127±12	97-157
DBP (mmHg)	771±9.0	52-96
Glucose (mmol/l)	5.06±0.55	4.1-7.0
Insulin (mU/l)	11.46±8.17	1.73-57.1
Cholesterol (mmol/l)	5.54±0.84	3.4-7.9
Triglycerides (mmol/l)	1.92±1.39	0.37-9.37
HDL cholesterol (mmol/l)	1.37±0.36	0.62-2.28
LDL cholesterol (mmol/l)	3.35±0.77	1.65-5.4
Cholesterol: LDL ratio	4.33±1.36	2.33-9.84
S-IMCL	16.0±7.2	4.4-50.4
T-IMCL	7.0±3.7	0.3-30.5
IHCL	5.5±12.5	0-108.7
Total fat (kg)	28.5±10.6	9.1-61.2
Subcutaneous (kg)	22.0±9.1	7.1-52.4
Internal (kg)	6.5±2.7	1.3-14.7
Subcutaneous abdominal (kg)	6.5±3.2	1.5-18.17
Subcutaneous peripheral (kg)	15.5±6.0	5.6-35.7
Visceral (kg)	3.8±1.9	0.39-10.4
Nonvisceral internal (kg)	2.8±0.97	0.87-6.2

Data presented as mean±SD. SD: Standard deviation, SBP: Systolic blood pressure, DBP: Diastolic blood pressure, WHR: Waist to hip ratio, BMI: Body mass index, CSA: Cross-sectional area, RA: Rectus abdominis, LDL: Low-density lipoprotein, HDL: High-density lipoprotein, S-IMCL: Soleus intramyocellular lipid, T-IMCL: Tibialis intramyocellular lipid, IHCL: Intrahepatocellular lipid, VO_{2max}: Maximal oxygen uptake