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Dummi Nadani Gunasinghe

University of Sri Jayewardenepura

Jeewantha Jayamali

University of Sri Jayewardenepura

Padukkage Harshani Chathurangika

University of Sri Jayewardenepura

Thashmi Nimasha

University of Sri Jayewardenepura

Lahiru Perera

University of Sri Jayewardenepura

Uvini Amarasekara

University of Sri Jayewardenepura

Rivindu H. Wickramanayake

University of Sri Jayewardenepura

Aayuka Panditharatne

University of Sri Jayewardenepura

Gathsaurie Neelika Malavige

University of Sri Jayewardenepura

Chandima Jeewandara

jeewandara@sjp.ac.lk

University of Sri Jayewardenepura

Research Article

Keywords:

Posted Date: June 10th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-9798808/v1>

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Additional Declarations: No competing interests reported.

Body composition and cardiometabolic risk in South Asians: sex-specific associations of visceral adiposity and lean muscle mass in Sri Lankan adults

Dummi Nadani Gunasinghe¹, Jeewantha Jayamali¹, Padukkage Harshani Chathurangika¹, Thashmi Nimasha¹, Lahiru Perera¹, Uvini Amarasekara¹, Rivindu H. Wickramanayake¹, Aayuka Panditharatne¹, Gathsaurie Neelika Malavige^{1,2#}, Chandima Jeewandara^{1,2#}

¹Institute of Allergology and Immunology University of Sri Jayewardenepura, ²Department of Immunology and Molecular Medicine, University of Sri Jayewardenepura, Gangodawila, Nugegoda, Sri Lanka

contributed equally as senior authors

Correspondence should be addressed to:

Prof. Chandima Jeewandara MBBS, PgDFM, MRCP (INT), MSc (Allergy), PhD

¹Institute of Allergology and Immunology University of Sri Jayewardenepura, Gangodawila, Nugegoda, Sri Lanka

Tel +94 (0) 777359740; Email: jeewandara@sjp.ac.lk

Abstract

Background: Given that South Asians account for approximately one-quarter of the global population and face a rapidly increasing burden of diabetes, cardiovascular disease, and obesity, characterizing body composition and its metabolic correlates in this population is of critical importance.

Methods: In this cross-sectional study, 131 Sri Lankan adults of varying physical activity (mean age 39.3 ± 10.7 years; 48 women) underwent body composition assessment using dual-energy X-ray absorptiometry to quantify visceral adipose tissue area, fat mass index, fat mass ratio, and appendicular lean mass index. Fasting blood glucose, lipid profile, apolipoproteins A1 and B, and inflammatory markers (interleukin-6 and interleukin-1 β) were analyzed.

Results: A high burden of visceral adiposity and adverse fat indices was observed, particularly among males. Visceral adipose tissue area ≥ 100 cm² was present in 48% of females and 77% of males, while fat mass index above the cut-off was observed in 69% of females and 93% of males; elevated fat mass ratio was present in 54% of females and 36% of males. In females, higher visceral adiposity and adverse fat indices were consistently associated with higher fasting blood glucose and an unfavourable apolipoprotein profile, including lower ApoA1 and higher ApoB (all $p < 0.05$). No significant associations between adiposity indices and metabolic or inflammatory markers were observed in males. Low appendicular lean mass was common in both sexes and, in males, was associated with higher ApoB, ApoB/ApoA1 ratio, and total cholesterol (all $p < 0.05$).

Conclusions: Visceral adiposity and low lean muscle mass are highly prevalent among South Asians and demonstrate sex-specific metabolic associations, underscoring the need for urgent public health strategies to address cardiometabolic risk and frailty.

Introduction

Cardiovascular diseases (CVD) resulting in stroke and ischaemic heart disease are the leading causes of death in Sri Lanka [1] and in South Asia [2]. The prevalence of CVD is predicted to increase by 109.0% from 2025 to 2050, with the crude mortality rates due to CVD predicted to increase by 85.3% in South Asia [3]. South Asia is expected to have the highest age-standardised mortality due to CVD (141 deaths per 100,000 population), by 2050 [3]. Obesity is an important risk factor for CVD and an individual is classified as overweight or obese based on an individual body mass index (BMI) [4]. Due to the differences in the body composition, the BMI cut-off values that define overweight and obesity are different for South Asian populations compared to individuals of Caucasian ethnicity [4]. However, the BMI has many limitations, as it is affected by the muscle mass of an individual and does not indicate the distribution of adiposity.

There is a marked increase in obesity and obesity related disorders in South Asia and Southeast Asia [5]. Obesity is associated with an increase in for developing CVDs, diabetes, cancers, obstructive sleep apnoea, dementia osteoarthritis and also is an important risk factor for development of severe disease in many infections [6-8]. However, there are many phenotypes of obesity and the distribution of fat, i.e. truncal vs subcutaneous fat, is associated with higher risk of CVD and many other diseases [9]. Furthermore, visceral adiposity when associated with a lower muscle mass (sarcopenic obesity), is associated with a higher risk of CVD and other metabolic diseases compared to those with a similar BMI, but a high muscle mass [9, 10]. Overweight individuals who have a higher amount of subcutaneous fat compared to visceral fat, are shown to have a lower risk of developing CVD [11]. Obese or overweight individuals, as defined by higher

BMI, who were younger with lower visceral fat and physically active are ‘metabolically healthy’ and are at lower risk of developing CVD [12, 13]. Adipose tissue distribution has shown to vary among different ethnic groups, with the varying risks of developing CVD [12]. Although the waist circumference has been shown to correlate well with visceral adiposity, it cannot differentiate between visceral adiposity and subcutaneous adiposity [11, 12]. In addition to distribution of adipose tissue reduced skeletal muscle mass and strength has shown to be an important risk factor for CVD and diabetes [14]. Individuals with high visceral fat and lower lean muscle mass and strength are considered to have sarcopenic obesity [14]. Redistribution of fat during aging along with sarcopenia leads to ‘inflammaging’ which is a chronic low grade inflammatory state, which results in an increased risk of developing CVD, type 2 diabetes, cancers and other obesity related complications [15].

There is wide variation in sarcopenia and fat distribution among different ethnic groups [16]. Owing to ethnic differences in adipose tissue distribution and lean muscle mass, existing thresholds used to define excess visceral adiposity, low lean mass, and sarcopenia may not be universally applicable. Ethnicity-specific cut-off values may therefore be required to more accurately assess the risk of cardiovascular disease, diabetes, and other obesity-related conditions. For example, lower BMI and waist circumference thresholds are already recommended for South Asians to define overweight, obesity, and central adiposity [17]. Data on the distribution of adiposity, lean muscle mass, and associated metabolic and inflammatory risk factors in South Asian populations living in their countries of origin and adhering to local dietary and lifestyle patterns remain limited. Given that South Asians comprise approximately 25% of the global population and are experiencing a rapidly increasing burden of diabetes, cardiovascular disease, and obesity,

characterizing body composition in both healthy individuals and those with metabolic disease is essential to better understand risk distribution in this population.

The measurement of adiposity and lean muscle indices by dual-energy X-ray absorptiometry (DEXA) is considered to be comparable to MRI and is currently the most widely used, and reliable method to assessing the body composition [18]. We therefore aimed to characterize adiposity and lean muscle mass indices, together with metabolic and inflammatory risk factors, in a South Asian population and to examine their associations with metabolic disease.

105 **Methods**

106 **Study design and participants**

107 This cross-sectional study recruited 131 adults over a 12-month period. Participants were identified
108 through open advertisements and direct approach by trained research assistants from two sampling
109 frames: staff of the University of Sri Jayewardenepura (approximately 2,500 employees) and
110 families registered at the University Family Practice Centre (approximately 3,000 individuals).
111 These sampling frames were selected to ensure broad geographic and sociodemographic
112 representation. Recruitment was conducted without prior knowledge of participants' metabolic
113 status. Participants were subsequently classified as having metabolic risk factors or not, according
114 to criteria defined by the International Diabetes Federation Task Force on Epidemiology and
115 Prevention (see below)[19] (see below).

116

117 **Data collection and laboratory analyses**

118 Anthropometric measurements and fasting blood sampling were performed in accordance with
119 standard operating procedures. Fasting blood glucose and lipid profiles were analysed using a fully
120 automated biochemistry analyser (Thermo Scientific Indiko). Serum interleukin-6, interleukin-1 β ,
121 and apolipoproteins A1 and B were quantified by enzyme-linked immunosorbent assay (ELISA;
122 Mabtech, Germany) in samples stored at -80°C, following the manufacturer's instructions.

123

124 **Sample size calculation**

125
$$n = \frac{N \cdot X}{X + N - 1} \text{ where } X = \frac{Z^2 p(1-p)}{MOE^2}$$

126 With $Z=1.96$ (95% confidence), $p=0.5$ (maximum variance), and margin of error (MOE)= 0.1.

127
$$X = \frac{1.96^2 \times 0.5 \times 0.5}{0.16^2} \approx 37.52$$

128 Sample size for FPC registrants-

129
$$X = \frac{3000 \times 37.52}{37.52 + 3000 - 1} \approx 37.07$$

130 Sample size for medical students and staff-

131
$$X = \frac{2500 \times 37.52}{37.52 + 2500 - 1} \approx 36.98$$

132 The presence of metabolic disease was defined based on criteria laid down by the International
133 Diabetes Federation Task Force on Epidemiology and Prevention [19]. Accordingly, those with a
134 waist circumference over the population cut-off values (≥ 80 cm for females and ≥ 90 cm for males),
135 triglycerides ≥ 150 mg/dL (1.7 mmol/L), an HDL < 40 mg/dL (1.0 mmol/L) in males; < 50 mg/dL
136 (1.3 mmol/L) in females, a systolic blood pressure of ≥ 130 and/or diastolic blood pressure of ≥ 85
137 mm Hg, or a FBS of ≥ 100 mg/dL [19].

138

139 **Inclusion and exclusion criteria**

140 Adults aged 20–80 years who were either employed at the university or registered as patients at
141 the Family Practice Centre were eligible to participate if they were able to attend the study site
142 following an overnight fast and undergo dual-energy X-ray absorptiometry (DXA),
143 anthropometric assessment, and venous blood sampling. Participants were excluded if they had a
144 known inflammatory or autoimmune disorder, advanced cardiac, hepatic, or renal disease, or had

undergone major surgery or hospitalisation within the preceding months, as these conditions could influence metabolic or inflammatory biomarkers. Individuals with orthopaedic implants likely to interfere with DXA measurements, those unable to comply with study procedures, or those unable to provide informed consent were also excluded.

Ethical considerations

Ethical approval was obtained from the Ethics Review Committee of the Faculty of Medical Sciences, University of Sri Jayewardenepura, Sri Lanka (62/19). Informed written consent was obtained from all the recruited individuals. Samples were collected and stored according to the ethical regulations. All methods were performed in accordance with the relevant guidelines and regulations.

Anthropometric measures

Body weight was measured using a calibrated digital scale (accuracy ± 0.1 kg; maximum capacity 150 kg) with participants wearing light clothing and no footwear. Height was measured barefoot using a stadiometer (accuracy ± 0.1 cm), with participants standing upright, heels against the wall, feet flat, and head positioned in the Frankfort plane. Waist circumference was measured using a non-stretchable tape at the midpoint between the lowest rib and the iliac crest at the end of a normal expiration. Hip circumference was measured at the level of the widest lateral extension of the pelvis. Body mass index (BMI) was calculated as weight divided by height squared (kg/m^2) and categorised using South Asian-specific cut-off values: underweight ($< 18.5 \text{ kg/m}^2$), normal weight ($18.5\text{--}23.8 \text{ kg/m}^2$), overweight ($23.9\text{--}27.5 \text{ kg/m}^2$), and obese ($\geq 27.5 \text{ kg/m}^2$) [17].

Dual energy Xray absorptiometry (DEXA) scanning to determine body composition

Whole-body DXA was performed using a Hologic Discovery W scanner (software v12.1) to assess body composition, including fat mass, lean mass, appendicular lean mass, and visceral adipose tissue area. Scans were conducted by a trained operator with calibration performed according to the NHANES Body Composition Analysis protocol [20]. Total body fat percentage was calculated as fat mass divided by total body mass, and visceral adipose tissue (VAT) area was quantified by delineating the abdominal muscular wall. Definitions and calculation methods for other body composition parameters are provided below.

Fat mass index (FMI)

Fat mass index assesses the body fat mass relative to height providing a more specific indication of the degree of adiposity in the body. [20]. associated with increased risk of developing metabolic diseases and cardiovascular diseases. FMI was calculated using the formula.

$$FMI = \frac{total\ fat\ mass(kg)}{height^2\ (m^2)}$$

Based on the FMI, individuals were classified as having a low, normal or high FMI. Accordingly, females, with a FMI of <5 kg/m² were considered as a low FMI, 5-9 kg/m² normal and > 9 kg/m² as high. Males with a FMI of <3 kg/m² were considered as having a low FMI, 3-6 kg/m² normal and > 6 kg/m² as high FMI [21].

Appendicular lean mass index (ALMI)

ALMI is measured to evaluate the skeletal muscle mass in the limbs relative to height [22]. The measurement is particularly important in identifying sarcopenia along with assessments of strength

[23]. ALMI was calculated using the formula and An ALMI of <5.5 was considered to indicate sarcopenia in females and a values <7 indicative of sarcopenia in males [24].

$$ALMI = \frac{\text{lean muscle mass in arms and legs}(kg)}{\text{height}^2(m^2)}$$

Skeletal muscle index (SMI)

Skeletal muscle mass index (SMI) was also evaluated in individuals, as it is a more reliable indicator of the lean muscle mass, as the ALMI under-estimates the presence of low muscle mass in obese and overweight individuals.

$$SMI = \frac{\text{Appendicular lean muscle mass (kg)}}{\text{height}^2 (m^2)}$$

Fat mass ratio (trunk to leg fat mass ratio)

The trunk-to-leg fat mass ratio assesses fat distribution, with a higher ratio indicating central adiposity linked to metabolic and cardiovascular risks.

$$\text{Fat mass ratio} = \frac{\text{Trunk fat mass (kg)}}{\text{Total fat mass of the legs(kg)}}$$

Statistical analysis

Statistical analyses were performed using GraphPad Prism (version 10.2.3) and R (version 4.3.1). Normality was assessed using the Shapiro–Wilk test, and all continuous variables were non-normally distributed ($p < 0.05$); therefore, non-parametric methods were applied throughout. Continuous variables are presented as median (IQR) and categorical variables as frequencies (%). Group comparisons were conducted using the Mann–Whitney U test, with rank-biserial correlation

(r) reported as the effect size. Associations between continuous variables were assessed using Spearman's rank correlation coefficient. Receiver operating characteristic (ROC) curves were generated to evaluate the ability of visceral adipose tissue area, fat mass index, and waist circumference to predict elevated fasting blood glucose (>100 mg/dL). Area under the curve (AUC), 95% confidence intervals, and sensitivity and specificity at the optimal Youden index cut-off were reported.

Patient and Public Involvement in Research

Patients or public were not involved in the design of the research, setting the research priorities, defining research questions or outcomes or in public dissemination of findings, as there is no such provision currently in Sri Lanka.

Results

Anthropometric measurements in the study population

48 (37%) of the individuals were females and 83 (63%) males. 31 (65%) of the females and 60 (72%) of the males had at least one metabolic risk factor defined by the International Diabetes Federation Task Force on Epidemiology and Prevention [19]. The basic demographic details and metabolic risk factors of the study population are shown in table 1.

Relationship between visceral fat and metabolic risk factors

In previous studies, those with a VAT area of $\geq 100 \text{ cm}^2$ were at a higher risk of developing obesity related metabolic disorders [25, 26]. We evaluated cardiometabolic risk factors and inflammatory mediators in participants with high visceral adipose tissue (VAT) area ($\geq 100 \text{ cm}^2$) compared with those below this threshold. High VAT was present in 23 (44%) females and 67 (77%) males. Among females, VAT $\geq 100 \text{ cm}^2$ was associated with older age (≥ 40 years; $p=0.03$), higher fasting blood glucose ($p=0.008$), and lower HDL cholesterol ($p=0.03$) and apolipoprotein A1 levels ($p=0.04$) compared with those with VAT $< 100 \text{ cm}^2$ (Table 2). In contrast, no significant differences in age, metabolic parameters, or inflammatory mediators were observed among males according to VAT category.

Cut-off values for visceral fat area and waist circumference associated with increase in the prevalence of the obesity-related disorders in South Asian populations

Although a visceral adipose tissue (VAT) area cut-off of ≥ 100 cm² has been proposed as a risk threshold for obesity-related diseases in several populations, studies in Southeast Asian populations, including Koreans, have identified a slightly higher cut-off (>103.8 cm²), which demonstrated a sensitivity of 74.5% and a specificity of 64.7% for predicting increased metabolic disease risk [25, 26]. To identify a clinically actionable threshold for risk stratification, we used the significant independent association between continuous visceral adipose tissue (VAT) area and elevated fasting blood glucose (OR 1.23 per 10 cm² increase; $p < 0.001$) to inform receiver operating characteristic (ROC) analysis. ROC curves were generated to determine the optimal VAT area cut-off values associated with the presence of metabolic risk factors in this population. VAT area was compared between participants with and without at least one metabolic risk factor, as defined by the International Diabetes Federation Task Force on Epidemiology and Prevention [19]. Receiver operating characteristics (ROC) analysis was performed to identify potential VAT area cut-off values associated with the presence of metabolic risk factors. In males, VAT area was higher among those with metabolic risk factors, although this difference did not reach statistical significance ($p = 0.056$), with an area under the curve (AUC) of 0.63. A VAT threshold of ≥ 99.8 cm² yielded a sensitivity of 80% and a specificity of 27.2% for identifying metabolic risk in males. In contrast, VAT area was significantly higher in females with metabolic risk factors ($p = 0.04$), with an AUC of 0.67.

Logistic regression analysis was performed to examine the independent association between visceral adipose tissue (VAT) mass and the presence of metabolic risk factors, given variability in initial correlation analyses. In males, VAT mass was higher among those with metabolic risk factors, but this association did not reach statistical significance ($p = 0.056$), with modest

discriminatory performance (AUC 0.63). In females, VAT mass was significantly associated with metabolic risk factors ($p=0.04$) and demonstrated similar discriminatory ability (AUC 0.67).

Given the significant independent association between continuous visceral adipose tissue (VAT) area and fasting blood glucose (Spearman's $r=0.392$, $p<0.0001$), we proceeded to identify VAT area cut-off values predictive of elevated fasting blood glucose (≥ 100 mg/dL) in males and females. VAT area was significantly higher in both males and females with fasting blood glucose ≥ 100 mg/dL (both $p<0.0001$), with good discriminatory performance (AUC 0.72 in males and 0.97 in females). In males, a VAT area threshold of ≥ 147 cm² yielded a sensitivity of 75% and specificity of 73% (likelihood ratio 2.7; Figure 1A). In females, a VAT area threshold of ≥ 132.5 cm² achieved 100% sensitivity and 93.6% specificity (likelihood ratio 14.3; Figure 1B).

Waist circumference correlated strongly with VAT area in both males (Spearman's $r=0.803$, $p<0.0001$) and females (Spearman's $r=0.77$, $p<0.0001$). A waist circumference cut-off of ≥ 89 cm was identified as optimal for predicting fasting blood glucose ≥ 100 mg/dL. In males, this threshold demonstrated 80% sensitivity and 58.7% specificity (likelihood ratio 1.94), while in females it achieved 100% sensitivity and 66.7% specificity (likelihood ratio 3.07).

Association of metabolic risk factors with other adiposity indices

Fat mass index (FMI) was used as a measure of overall adiposity. An FMI above the cut-off was present in 69% of females (≥ 9) and 93% of males (≥ 6), with no age differences between groups. In females, FMI ≥ 9 was associated with higher fasting blood glucose compared with FMI <9 ($p=0.05$; Sup table 1), while no significant differences in metabolic or inflammatory markers were observed in males.

The fat mass ratio (FMR) has been used to diagnose lipodystrophy in HIV patients on anti-retroviral therapy and the cut off values indicating lipodystrophy in different populations vary from 1.5 in Caucasian males in France [27] and 1.96 in Portuguese men and 1.33 in Portuguese women [28]. Recently, the FMR has also shown to associate with metabolic risk factors and biomarkers and was found to associate with diabetes in the absence of obesity [13]. Therefore, based on the recent large study carried out in the UK Biobank study participants, we used a FMR ≥ 1.7 in male participants and ≥ 1.2 in female participants to indicate potential lipodystrophy [13]. 26 (54%) females had an FMR above the cut-off value (≥ 1.2), while 30 (36%) males had an FMR above the cut-off value (≥ 1.7).

The metabolic characteristics and inflammatory mediators of those with a high FMR is shown in table 3. There was no difference in the age in females or males with an FMR above the cut-off value that indicated lipodystrophy. Females with an FMR of ≥ 1.2 demonstrated significantly higher FBS ($p=0.003$, $r_{rb}=-0.51$) and ApoB ($p=0.01$, $r_{rb}=-0.42$) levels along with significantly higher Apo B/A1 levels ($p=0.003$, $r_{rb}=-0.38$) compared to the FMR < 1.2 group (sup table 1). There were no differences in metabolic risk factors or inflammatory mediators in men with a FMR of ≥ 1.7 .

As the cut-off values defined by Agrawal et al [13] did not appear to associate with any metabolic derangement in males, we sought to identify FMR cut-off values for males and females in the Sri Lankan population, that may associate a FBS of ≥ 100 mg/dl. The FMR was significantly higher in males ($p=0.009$, AUC=0.68) and females ($p=0.01$, AUC=0.84) with a FBS of ≥ 100 mg/dl. In males a FMR of ≥ 1.61 had a sensitivity of 75% and a specificity of 58.7% with a FBS of ≥ 100 mg/dl, with a likelihood ratio of 1.82 (Fig 1C). In females a FMR of ≥ 1.32 had a sensitivity of 80% and a specificity of 76.6% with a FBS of ≥ 100 mg/dl, with a likelihood ratio of 3.4 (Fig 1D).

Skeletal muscle mass and related indices in females and males of South Asian origin

Appendicular lean mass index (ALMI), which reflects skeletal muscle mass relative to height and is used in the assessment of sarcopenia, was below the cut-off in 32 (67%) females (<5.5) and 44 (53%) males (<7). No significant differences in metabolic or inflammatory markers were observed in females according to ALMI category. In contrast, males with low ALMI (<7) had significantly higher apolipoprotein B levels, ApoB/ApoA1 ratio, and total cholesterol compared with those with $ALMI \geq 7$ (Table 3).

Sarcopenic obesity and metabolic and inflammatory risk factors

As handgrip strength was not assessed, potential sarcopenic obesity (SO) was defined using combined appendicular lean mass index (ALMI) and fat mass ratio (FMR) criteria. Females with $ALMI \leq 5.5$ and $FMR \geq 1.2$, and males with $ALMI \leq 7$ and $FMR \geq 1.7$, were classified as having potential SO. Using these criteria, 20 (42%) females and 12 (14%) males had potential SO. No significant differences in metabolic risk factors or inflammatory mediator levels were observed between those with and without potential SO (Table 4).

Serum interleukin-6 (IL-6) levels showed inverse correlations with HDL cholesterol ($r=-0.26$, $p=0.003$), apolipoprotein A1 ($r=-0.21$, $p=0.02$), and apolipoprotein B ($r=-0.27$, $p=0.001$). Interleukin-1 β did not correlate with metabolic or anthropometric parameters. Apolipoprotein A1 was inversely correlated with ALMI ($r=-0.33$, $p<0.0001$), waist circumference ($r=-0.29$, $p=0.0008$), and visceral adipose tissue area ($r=-0.19$, $p=0.03$), while apolipoprotein B was positively correlated with ALMI ($r=0.30$, $p=0.0005$) and FMR ($r=0.30$, $p=0.002$).

Discussion

In this study, we characterized adiposity and lean muscle mass indices in Sri Lankan women and men and compared these measures with conventional anthropometric indices, including BMI and waist circumference. We further examined the associations of visceral adipose tissue (VAT), preferential truncal fat distribution (fat mass ratio), and lean muscle mass with metabolic risk factors and inflammatory mediators. Among women, higher VAT area and fat mass ratio were associated with elevated fasting blood glucose and lower HDL cholesterol and apolipoprotein A1 levels. In contrast, no significant associations were observed between adiposity measures and metabolic or inflammatory markers in men. Instead, men with lower skeletal muscle mass, reflected by an appendicular lean mass index below established cut-offs, exhibited higher total cholesterol, apolipoprotein B levels, and ApoB/ApoA1 ratios—markers strongly associated with cardiovascular disease risk [29]. In contrast, women with appendicular lean mass index values below the established cut-offs did not demonstrate adverse metabolic or inflammatory profiles. The observed sex-specific pattern—where adiposity indices independently associated with metabolic risk in women, while lean muscle mass indices independently associated with dyslipidaemia in men—warrants further investigation. These findings suggest that reduced lean muscle mass may play a disproportionately important role in dyslipidaemia risk among men compared with women, a hypothesis that requires confirmation in larger, longitudinal studies.

Although healthy individuals in the community were recruited from open advertisement, 62% of the females and 75% of the males had at least one metabolic risk factor defined by the International Diabetes Federation Task Force on Epidemiology and Prevention [19]. A high prevalence of

adverse adiposity profiles was observed, with 44% of females and 77% of males having a visceral adipose tissue (VAT) area ≥ 100 cm², 65% of females and 91% of males exhibiting fat mass index values above established cut-offs, and 58% of females and 38% of males demonstrating an unfavourable fat mass ratio. These findings indicate a substantial burden of obesity and maladaptive fat distribution in this South Asian population. Given the relatively young mean age of participants (38.5 years in females and 39.7 years in males), these patterns highlight a population at heightened risk for future cardiometabolic diseases, including cardiovascular disease, diabetes, and obesity-related malignancies. This is particularly concerning in Sri Lanka, where cardiovascular disease remains the leading cause of mortality. [1] and in South Asia [2], extensive public health programs would be required to reduce the burden of these diseases in these countries. Furthermore, low grade inflammation and insulin resistance is also associated with an increased risk of breast, colorectal, endometrial, pancreatic, prostate cancer and many haematological malignancies [30]. Therefore, given the marked increase in these diseases associated with an increase in visceral adiposity, urgent measures are required to advocate healthy lifestyle, exercise and healthy eating habit for prevention of these diseases.

65% females and 54% males had an ALMI below the cut-off value. Although a lower ALMI was not associated with an increase in metabolic risk factors in females, a lower ALMI is associated with reduction in strength, aerobic capacity ultimately resulting in a reduction in functional capacity [31]. Although we did not test the muscle strength in the study population, a reduced lean muscle mass in younger adults or middle-aged adults is likely to lead to an increase in frailty as individuals age. The reasons for most individuals in this study having a lean muscle mass, below the range associated with sarcopenia could be due to multiple factors such as lack of any physical

activity or due to ongoing chronic inflammation and insulin resistance [31]. Reduced lean muscle mass may impair functional capacity, thereby limiting engagement in physical activity and perpetuating a cycle of increasing visceral adiposity, further muscle loss, and heightened risk of obesity-related diseases. Although no significant differences in metabolic or inflammatory markers were observed in participants with potential sarcopenic obesity in this study, larger longitudinal studies are needed to establish population-specific cut-off values for fat mass ratio and appendicular lean mass index in South Asians, which would support earlier risk identification and targeted intervention strategies.

In summary, a substantial proportion of this population exhibited adverse body composition, with high visceral adiposity observed in 44% of females and 77% of males, and fat mass above cut-off values in 91% of males. Maladaptive fat distribution, characterised by preferential truncal adiposity, was present in 58% of females and 38% of males, while low lean muscle mass within the sarcopenic range was identified in 65% of females and 54% of males. In the context of the rapidly increasing burden of cardiovascular disease, diabetes, and obesity-related conditions in South Asia, these findings underscore the need for urgent public health strategies to mitigate cardiometabolic risk and preserve functional capacity.

Ethics approval and consent to participate

The study was approved by the Ethics review Committee of the University of Sri Jayewardenepura, Sri Lanka. All subjects and their parents/guardians gave informed written consent. The study adhered to the Declaration of Helsinki.

402 **Consent for publication**

403 Not applicable.

404 **Availability of data and materials**

405 All relevant data is available within the manuscript and supplementary files.

406 **Competing interests**

407 Authors have no competing interests.

408 **Funding**

409 We are grateful to the University of Sri Jayewardenepura Sri Lanka (grant number
410 ASP/01/RE/MED/2019/50).

411 **Authors' contributions**

412 Conceptualization: CJ, GNM

413 Project administration: CJ, GNM

414 Data curation: DNG, JJ, PHC, TN, LP, UA, RHW, AP

415 Laboratory assays: DNG, UA

416 Data analysis: DNG, GNM

417 Funding acquisition: CJ

418 Writing the original draft: GNM, DNG

419 Reviewing and editing the manuscript: DNG, GNM, CJ

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Tables

Table 1: Demographic and laboratory characteristics with anthropometric measures of the study population.

Characteristic	Females N (%)	Males N (%)
Age (mean, $\pm$ SD)	38.6 $\pm$ 11	39.8 $\pm$ 10.7
FBS >100mg/dL	5 (10%)	22 (27%)
Total cholesterol $\geq$ 200mg/dL	28 (58%)	47 (57%)
HDL ($\leq$ 40mg/dL in males and $\leq$ 50mg/dL in females)	19 (40%)	29 (35%)
LDL $\geq$ 100 mg/ dL	39 (81%)	70 (84%)
Triglycerides $\geq$ 150mg/dL	4(8%)	14 (17%)
Waist circumference ($\geq$ 80cm in females and $\geq$ 90cm in males)	18 (38%)	41 (49%)
BMI		
<18.5 kg/m ²	1 (2%)	3 (4%)
$\geq$ 23.9 kg/m ²	19 (40%)	49 (59%)

540 **Table 2: Association of metabolic risk factors VAT area in males and females**

	Females		P value	Males		P value
	VAT <100	VAT ≥ 100		VAT <100	VAT ≥100	
Age	35.4±10.2	41.0±11.2	0.112	37.1±11.7	40.6±10.3	0.244
HDL	59.0(47.0–74.0)	48.0(40.0–59.0)	0.078	44.0(37.0–53.5)	42.0(36.0–52.2)	1
LDL	132.0(112.0–144.0)	124.0(101.0–159.5)	0.556	133.0(120.0–165.0)	137.0(117.0–167.2)	0.922
Total Cholesterol	205.0(195.0–230.0)	194.0(170.5–213.5)	0.173	195.0(176.5–232.0)	209.5(189.8–234.5)	0.346
FBS	86.0(84.0–91.0)	90.0(86.5–98.0)	0.021	89.0(86.5–95.0)	91.0(86.0–102.2)	0.266
ApoA1	162.0(130.0–190.0)	140.0(118.5–161.5)	0.072	130.0(107.0–156.0)	125.5(108.8–150.0)	0.905
ApoB	78.0(73.0–98.0)	80.0(73.0–100.5)	0.926	102.0(78.0–118.0)	95.5(85.0–112.0)	0.948
ApoB/Apo A1 ratio	0.5(0.4–0.8)	0.6(0.4–0.8)	0.302	0.8(0.7–1.1)	0.8(0.6–1.0)	0.935
IL-6	12.5(7.5–22.5)	16.7(10.0–35.9)	0.197	15.2(12.8–25.5)	12.5(6.4–23.2)	0.169
IL-1β	4.2(3.0–5.6)	4.2(2.9–5.3)	0.718	4.2(2.9–5.0)	3.9(3.0–5.6)	0.858

BMI	22.5(20.5–24.5)	24.0(22.5–26.0)	0.027	22.5(21.5–26.0)	24.5(22.5–27.5)	0.287
Waist circumference	74.0(70.5–81.0)	85.0(80.5–90.5)	<0.0001	86.0(77.0–93.5)	91.0(84.0–96.0)	0.119

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557 **Table 3: Association of metabolic risk factors with ALMI in males and females of South Asian**
558 **origin**

	Females		P value	Males		P value
Median, (IQR)	ALMI< 5.5	ALMI≥5.5		ALMI<7	ALMI ≥7	
Age	38.6±12.1	37.0±8.4	0.793	40.0±12.6	39.6±8.2	0.852
HDL	59.5(44.0–71.8)	48.5(40.5–53.5)	0.041	44.0(37.8–53.2)	42.0(36.0–51.5)	0.55
LDL	126.0(100.0–159.5)	130.5(105.8–148.0)	0.555	135.0(114.8–153.0)	150.0(123.5–181.0)	0.06
Total Cholesterol	204.5(181.2–229.2)	194.5(171.2–212.5)	0.255	197.5(179.5–221.2)	216.0(194.0–246.5)	0.014
FBS	90.0(85.0–94.2)	86.5(83.5–90.5)	0.228	91.0(86.0–99.0)	90.0(86.5–105.5)	0.869
ApoAI	161.0(126.8–187.0)	139.0(121.5–154.8)	0.061	125.5(111.0–150.8)	126.0(106.5–147.5)	0.587
ApoB	77.5(72.8–99.0)	80.0(73.0–99.2)	0.922	89.5(74.8–110.5)	103.0(89.0–121.0)	0.024

ApoB/ApoAI ratio	0.6(0.4– 0.8)	0.6(0.5–0.8)	0.33	0.8(0.5–1.0)	0.9(0.7–1.1)	0.066
IL-6	13.1(7.3 –24.0)	15.6(11.8– 42.6)	0.294	13.8(10.4–2 3.5)	12.4(6.0–26. 2)	0.275
IL-1 β	4.3(3.0– 5.3)	3.6(2.7–5.6)	0.685	3.9(3.0–5.1)	4.2(2.5–5.7)	0.938
BMI	22.5(20. 5–24.0)	25.0(23.5– 27.0)	0.001	23.5(22.0–2 4.5)	27.0(25.0–2 9.0)	<0.0001
Waist circumference	77.0(70. 5–81.0)	79.0(74.0– 84.0)	0.125	86.0(81.0–9 2.0)	94.0(88.0–1 01.0)	<0.0001

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569 **Table 4: Metabolic risk factors and inflammatory markers in those with and without**
570 **sarcopenic obesity.**

	Females		P value	Males		P value
Median, (IQR)	Potential Sarcopeni c obesity+	Potential Sarcopenic obesity -		Potential Sarcopenic obesity+	Potential Sarcopenic obesity -	
Age	40.8±12.9	36.1±9.1	0.225	41.9±7.6	39.4±11.1	0.334
HDL	50.0(40.8 –62.2)	52.5(46.0– 64.8)	0.707	44.5(41.0–4 9.0)	42.0(36.0– 53.0)	0.785
LDL	131.5(110 .8–161.0)	128.0(101. 5–143.2)	0.616	137.0(124.5 –147.8)	136.0(118. 0–173.5)	0.368
Total Cholesterol	204.0(186 .5–229.5)	197.5(174. 2–218.8)	0.53	200.0(193.2 –219.5)	207.0(184. 5–241.5)	0.488
FBS	91.0(85.8 –95.2)	88.0(84.0– 91.2)	0.055	88.5(84.8–1 02.0)	90.0(87.5– 99.5)	0.722
ApoA1	142.5(118 .0–171.2)	151.5(129. 8–177.0)	0.601	124.5(120.0 –141.8)	126.0(105. 0–150.0)	0.679
ApoB	91.0(75.0 –109.0)	77.0(68.8– 96.0)	0.084	90.5(73.8–1 02.0)	97.0(85.0– 117.0)	0.209
ApoB/ApoA 1 ratio	0.6(0.5–0. 9)	0.6(0.4–0.8)	0.129	0.7(0.6–0.8)	0.8(0.6–1. 0)	0.172

IL-6	12.4(7.9–19.0)	15.9(7.4–33.4)	0.32	17.8(11.6–28.6)	13.4(7.3–22.9)	0.361
IL-1 β	3.9(2.7–5.3)	4.2(3.0–5.6)	0.408	3.8(3.0–5.1)	4.2(3.0–5.4)	0.751
BMI	22.5(22.0–23.2)	24.0(21.8–26.2)	0.127	24.0(22.8–24.3)	24.0(22.1–28.0)	0.463
Waist circumference	80.5(74.0–81.2)	74.0(69.8–83.2)	0.248	91.5(87.8–94.2)	89.0(83.5–95.5)	0.354

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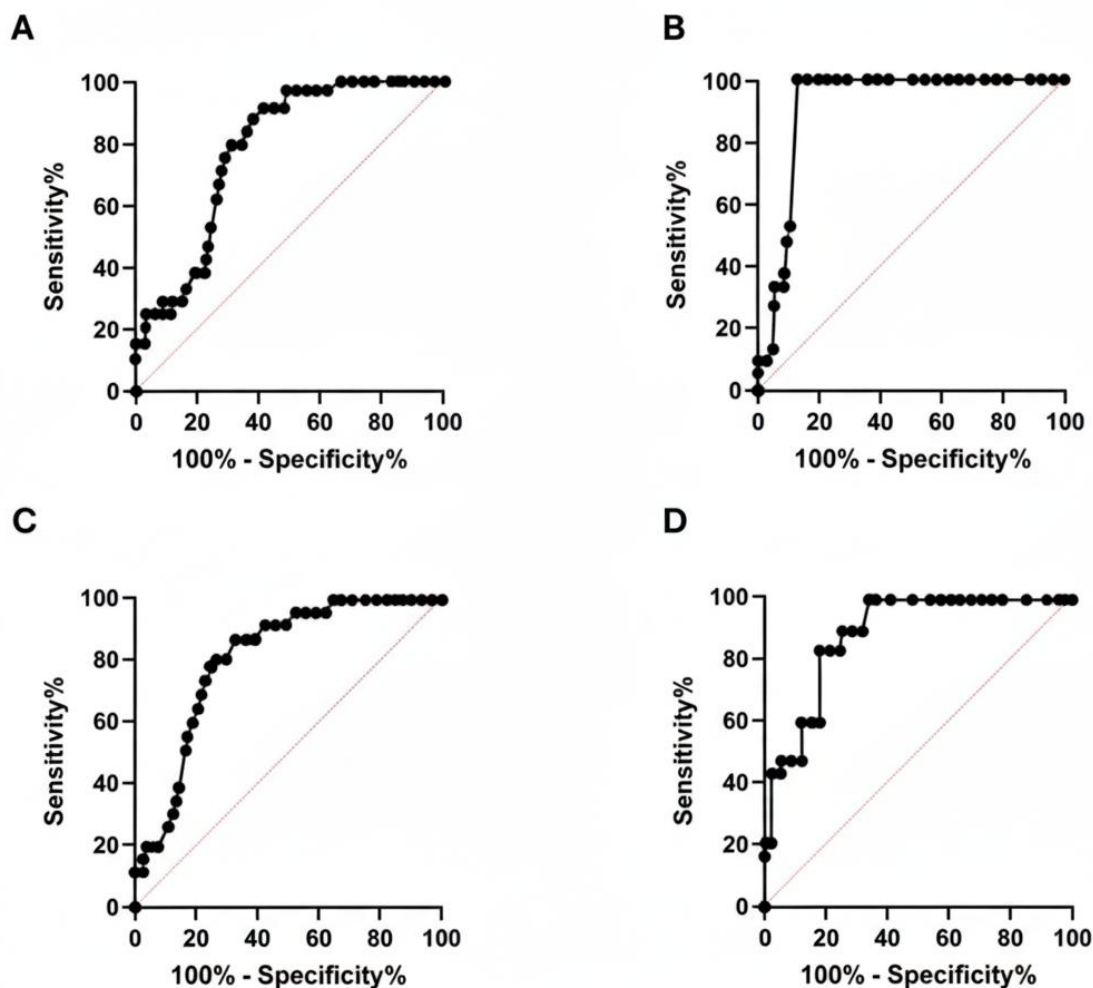
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586 **Figure**



587
 588 **Figure 1. ROC curves for VAT area and FMR in predicting elevated FBS in Sri Lankan**
 589 **adults**

590 Receiver operating characteristic (ROC) curves illustrating the diagnostic performance of visceral
 591 adipose tissue (VAT) area and fat mass ratio (FMR) in predicting elevated FBS in Sri Lankan males
 592 (n=83) and females (n=48). (A) VAT area in males: AUC=0.7, $p<0.0001$; cut off $\geq 147\text{cm}^2$ yielding
 593 75% sensitivity, 73% specificity and a likelihood ratio of 2.8. (B) VAT area in females: AUC=0.9,
 594 $p<0.0001$; cut off $\geq 132\text{cm}^2$ with 100% sensitivity, 93.6 specificity, and a likelihood ratio of 14.3.
 595 (C) FMR in males: AUC=0.68, $p=0.009$; cut off ≥ 1.62 achieving 75% sensitivity, 58.7%

596 specificity, and a likelihood ratio 1.82. (D) FMR in females: AUC=0.84, $p=0.001$; cut off ≥ 1.26
597 achieving 100% sensitivity, 60.5% specificity, and a likelihood ratio of 2.53.

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