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Original Research Article

Role of CT in Obesity: Scanning the Scene for Metabolic Syndrome Clues

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Abstract:

Objective: This study aims to evaluate the relationship between visceral fat volume (VFV), subcutaneous fat volume (SVF), and total abdominal fat volume with metabolic syndrome, using CT and contrast-enhanced CT (CECT) of the abdomen and pelvis.

Methods: A retrospective study was conducted, including 112 patients referred for abdominal CT scans between January 2023 and May 2024. Patients were categorized into two groups: Group 1, with metabolic syndrome, and Group 2, without. Inclusion criteria included individuals with hyperinsulinemia or hyperglycemia and at least two additional metabolic risk factors. Abdominal fat volumes were measured at the L4-L5 intervertebral disc level using a 128-slice MDCT scanner and a segmentation algorithm to distinguish visceral and subcutaneous fat volumes. Statistical analysis was performed using independent sample t-tests and Pearson's correlation tests.

Results: Group 1 had significantly higher VFV, SVF, and total fat volume compared to Group 2 ($p = 0.001$). A notable male predominance (61.6%) was observed, with significant gender-specific differences in fat volume distributions. Group 1 exhibited larger VFV, SFV, and total fat volumes in both males and females, with higher VFV particularly in females. No correlation was found between BMI and VFV, SVF, or total fat volume. VFV in females showed a strong association with metabolic syndrome.

Conclusions: Abdominal CT is an effective tool for assessing metabolic syndrome risk through quantification of VFV, SVF, and total fat volume, providing a more reliable assessment than BMI. These findings suggest that CT imaging may play a vital role in early detection and intervention for metabolic syndrome, allowing for improved clinical outcomes.

Keywords: Metabolic Syndrome, Visceral Fat Volume (VFV), Subcutaneous Fat Volume (SVF), Cardiometabolic Risk, Insulin Resistance, Abdominal Obesity, Body Mass Index (BMI).

Introduction

Abdominal obesity significantly contributes to the onset of metabolic syndrome, regardless of overall obesity status. Abdominal obesity, diminished glucose tolerance, hypertriglyceridemia, low high-density lipoprotein levels, and raised blood pressure are the risk factors linked to metabolic syndrome; a diagnosis requires the presence of at least three of these symptoms.

Metabolic syndrome elevates the risk of type 2 diabetes mellitus, cardiovascular disease, and both cardiovascular and overall mortality. Metabolic syndrome is linked to hepatic illness, renal failure, neurological impairment, and cancers. Approximately 20% to 25% of the global adult population is estimated to have metabolic syndrome. Thus, a significant aspect of the pathogenesis of metabolic diseases pertains to central adipose accumulation. Visceral and subcutaneous adipose tissues in the abdomen have unique metabolic risk profiles. Subcutaneous Adipose Tissue (SAT) is located between the dermis and the aponeurosis and fascia of muscles, providing cushioning and insulation, whereas Visceral Adipose Tissue (VAT) surrounds the internal organs.

VAT is believed to have a more significant impact than SAT on the proinflammatory condition and insulin resistance associated with metabolic syndrome, and it is linked to dyslipidemia, hyperinsulinemia, and glucose intolerance. The association between visceral adipose tissue and cardiometabolic risks is stronger than that of subcutaneous adipose tissue. Moreover, the actual volume of visceral adipose tissue serves as a superior indication of metabolic syndrome when

contrasted with visceral adipose area. Fat is deposited in visceral adipose tissue when subcutaneous adipose tissue reaches saturation.

A recent cohort research with a 9.3-year follow-up indicated that those in the middle and high tertiles of visceral fat had an elevated risk of cardiovascular disease (CVD). Nevertheless, no substantial association was seen between subcutaneous fat and cardiovascular disease occurrences. Moreover, Wander et al. identified a correlation between visceral fat and glucose intolerance. Previous study by Lee et al. and Sandeep et al. has shown a stronger association between visceral adipose tissue and metabolic syndrome (MS). MRI, CT, and other imaging modalities serve as reference techniques for evaluating abdominal adiposity due to their capacity for direct assessment of adipose tissue. CT and MRI enable superior anatomical distinction of bodily compartments and facilitate volumetric evaluation.

MRI-derived adipose tissue area is a valid diagnostic of metabolic syndrome and demonstrates a superior connection with the disease compared to BMI. MRI is more expensive and time-intensive than CT. Single-section measures have a strong correlation with volumetric measurements and provide the benefits of reduced computational intensity, shorter imaging duration, and less radiation exposure. Fat volume may be quantified at a single sectional level, generally at L3 or L4. CT is rapid and consistently repeatable, since fat has a universal attenuation range of -190 to -30 HU.

The visceral fat area (VFA) assessed using single axial CT underpins the diagnostic criteria for abdominal obesity as outlined in other investigations. Nonetheless, single slice imaging may lack the precision of whole volume imaging in identifying longitudinal variations in abdominal adiposity.

Numerous validation studies have shown that assessing Visceral Fat Volume (VFV) with CT is both feasible and highly reliable. Research on the relationship between true adipose volume and metabolic diseases remains insufficient. This study aimed to assess the correlation between visceral fat volume (VFV), subcutaneous fat volume (SVF), and total abdominal fat volume using CT and contrast-enhanced CT (CECT) of the pelvis and abdomen. This technology is more cost-effective and time-efficient for acquiring pictures compared to magnetic resonance imaging (MRI).

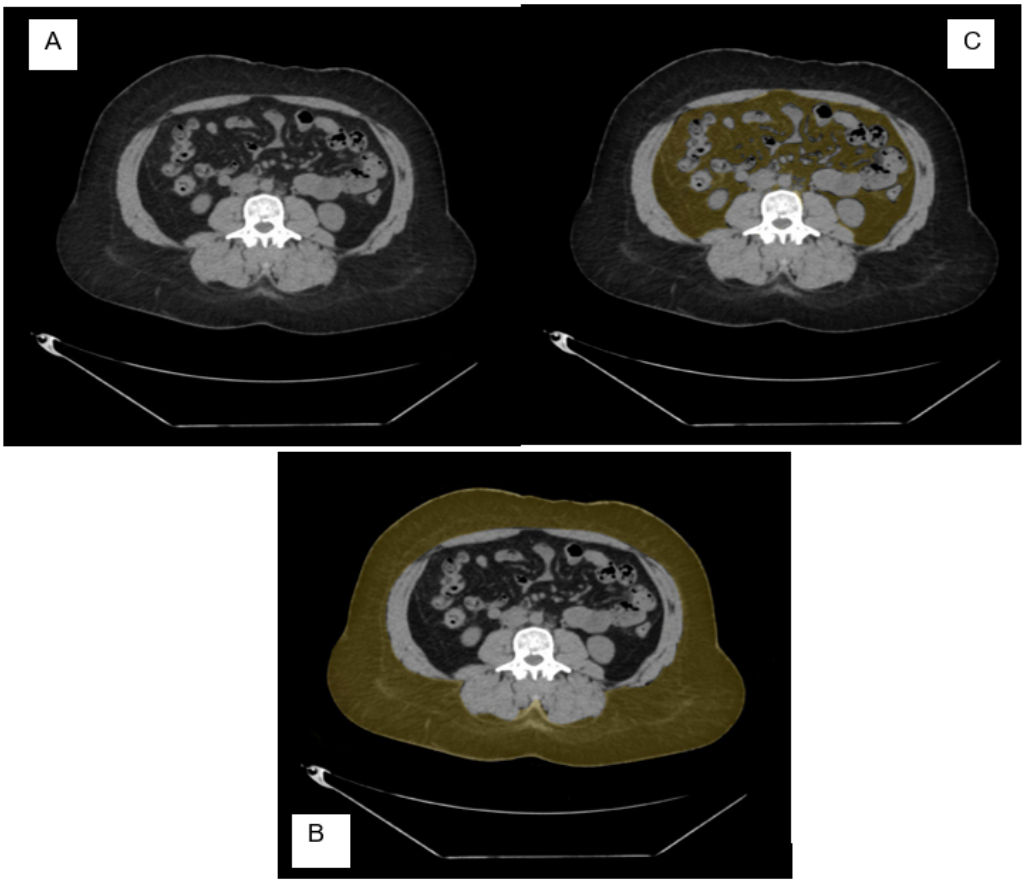

Figure 1:

A 55-year-old female patient with hypertension and diabetes with waist circumference of 101 cm and BMI of 35. Axial sections of abdominal CT showing (A) subcutaneous and visceral fat distribution, (B) subcutaneous fat volume (yellow coloured area), and (C) visceral fat volume (yellow coloured area)

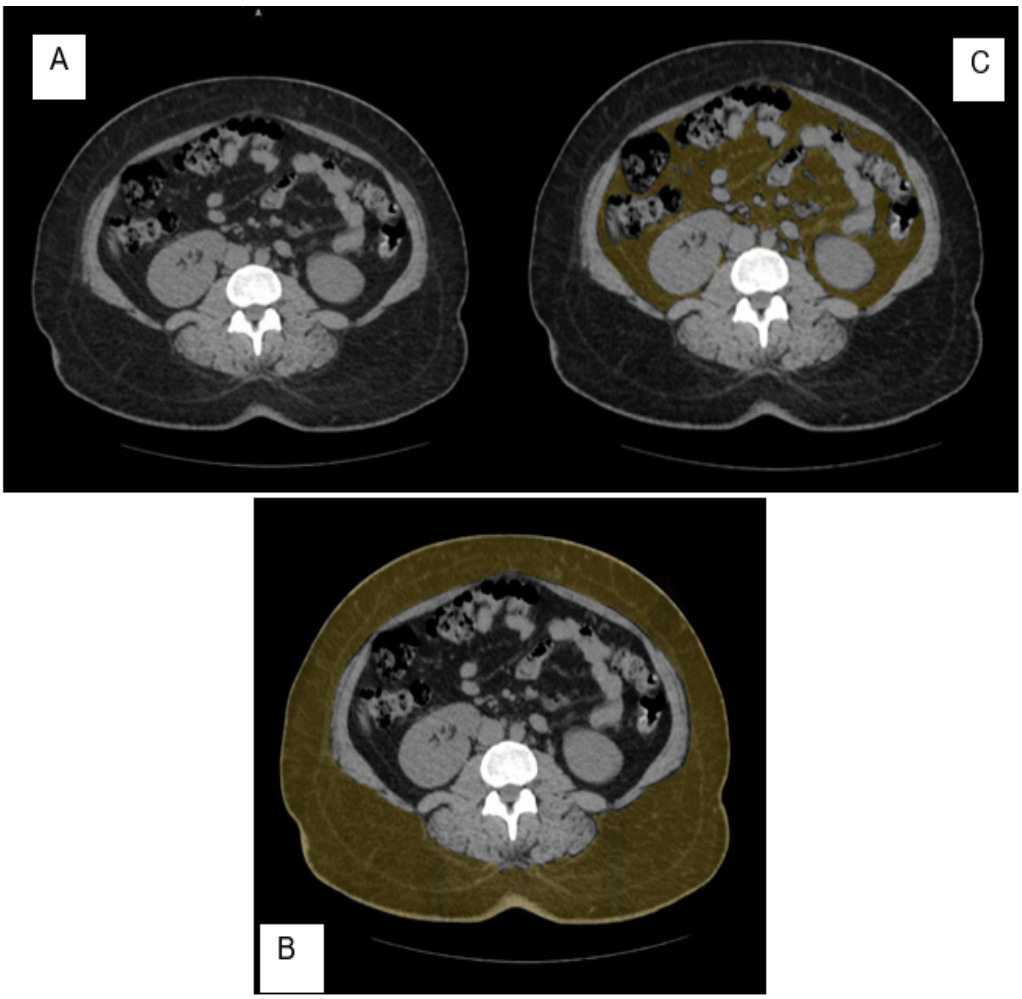

Figure 2:

A 45-year-old female patient with hypertension and dyslipidaemia with waist circumference of 99 cm and a BMI of 32. Axial sections of abdominal CT showing (A) subcutaneous and visceral fat distribution, (B) subcutaneous fat volume (yellow coloured area), and (C) visceral fat volume (yellow coloured area).

Material and Methods

A retrospective study was done and CT / CECT Abdomen studies done between January 2023 and May 2024 were included and estimation of visceral fat, subcutaneous fat, and total fat volume using multislice CT (MSCT)/CECT scans of the abdomen and pelvis were performed.

A total of 112 patients were included in the study, who were referred for CT abdomen for evaluation of abdominal pathologies.

Patients were categorized as Group 1 and Group 2 as per the inclusion and exclusion criteria detailed below.

Inclusion criteria

All patients aged between 25 to 85 years with hyperinsulinaemia (the upper fourth of the fasting insulin level among nondiabetic subjects) or hyperglycaemia (fasting glucose ≥ 110 mg/dl) in addition to at least 2 of the following: waist girth ≥ 94 cm, dyslipidaemia (triglycerides ≥ 150 mg/dl or HDL cholesterol < 40 mg/dl), or BP ≥ 140/90 mmHg or taking anti-hypertensives were included as cases and designated as Group 1 (i.e. those with metabolic syndrome).

Exclusion criteria

Patients without diabetes, hypertension, or dyslipidaemia (taken as individual parameters or a combination of 2) were considered as controls. These patients were categorized as Group 2 (i.e. those without metabolic syndrome). Patients with ascites or other causes of abdominal distention (e.g. tumours) and fat stranding (e.g. pancreatitis) were excluded from the study.

Methodology

The patients in these groups underwent CT or contrast-enhanced CT scans, for variable suspected pathologies based on clinical symptoms, utilizing a 128-slice MDCT scanner (GE).

One radiologist— with 7 years of experience — examined the studies on imaging in the precontrast CT analysis; fat was defined as pixels falling within the range of -250 to -50 Hounsfield units; subcutaneous fat was described as the extraperitoneal fat located between the muscles and skin. Visceral fat was described as the part within the abdomen having a density to subcutaneous fat. Total fat refers to the amount of fat encompassed by both visceral and subcutaneous fat layers.

A segmentation algorithm based on region growing was utilized in this process. In using a cursor to place an ROI over a grey scale range the post processing software in the 128 slice MDCT scanner (GE) automatically selected all pixels, with similar grey levels to the one chosen. The program then displayed the quantity of fat in the area distinguishing between visceral and subcutaneous fat layers.

Volume measurements of subcutaneous fat (SF), total fat and visceral fat (VF) were conducted at the L4 L5 intervertebral disc level and then compared to determine any association with the occurrence of metabolic syndrome as, per clinical standards.

Sample size calculation

Based on the effect size of the volume between the groups being 0.57, an error of 5%, and power of 80%, the sample size was assessed to be 51 in each group. We also took into consideration the effect size of the area difference as a substitute for the volume because the volume difference was never addressed. By measuring mean differences of at least 30 cm^2 of VFA between individuals with and without metabolic syndrome, and taking into account the standard deviation of VFA in those with and without metabolic syndrome, which are 63.4 and 42.1, respectively, the effect size for the area difference between metabolic syndrome and non-metabolic syndrome was calculated.

Statistical analysis

IBM SPSS (Statistical package for social sciences) Statistics V20.0 (IBM Corp., 2011) was used for statistical analysis after data were imported into Microsoft Excel. The independent sample t-test and Pearson's correlation test were used for statistical analysis.

Table 1: Comparison of the mean parameters between the groups using independent sample t-test

	Groups	n	Mean	SD	p-value
Height (M)	A	52	1.64	0.081	0.689
	B	60	1.67	0.089	
Weight (Kg)	A	52	71.79	10.43	0.565
	B	60	70.48	11.48	
BMI (Kg/m2)	A	52	27.18	3.52	0.516
	B	60	26.67	3.87	

Table 2: Comparison of the mean parameters between the groups using independent sample t-test

Value	Groups	N	Mean	SD	P-Value
Visceral fat volume (cc)	A	52	681.12	92.585	0.001*
	B	60	532.36	107.086	
Subcutaneous fat	A	52	1717.28	285.006	0.001*
	B	60	931.22	233.006	
Total fat volume (cc)	A	52	2389.95	290.233	0.001*
	B	60	1464.27	306.084	

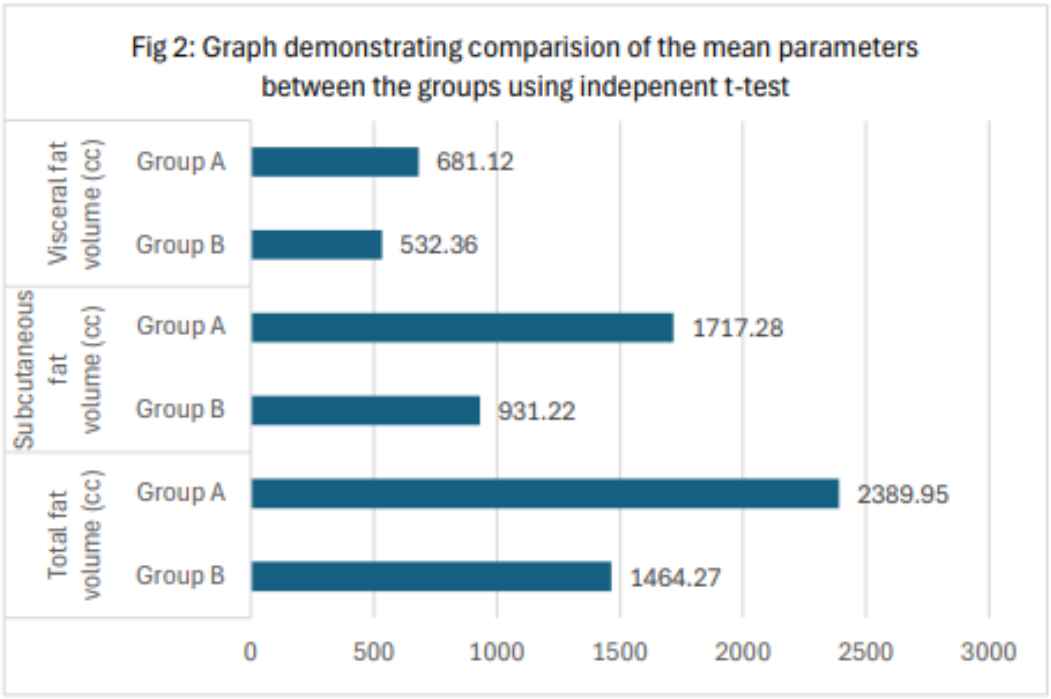

Figure 3:

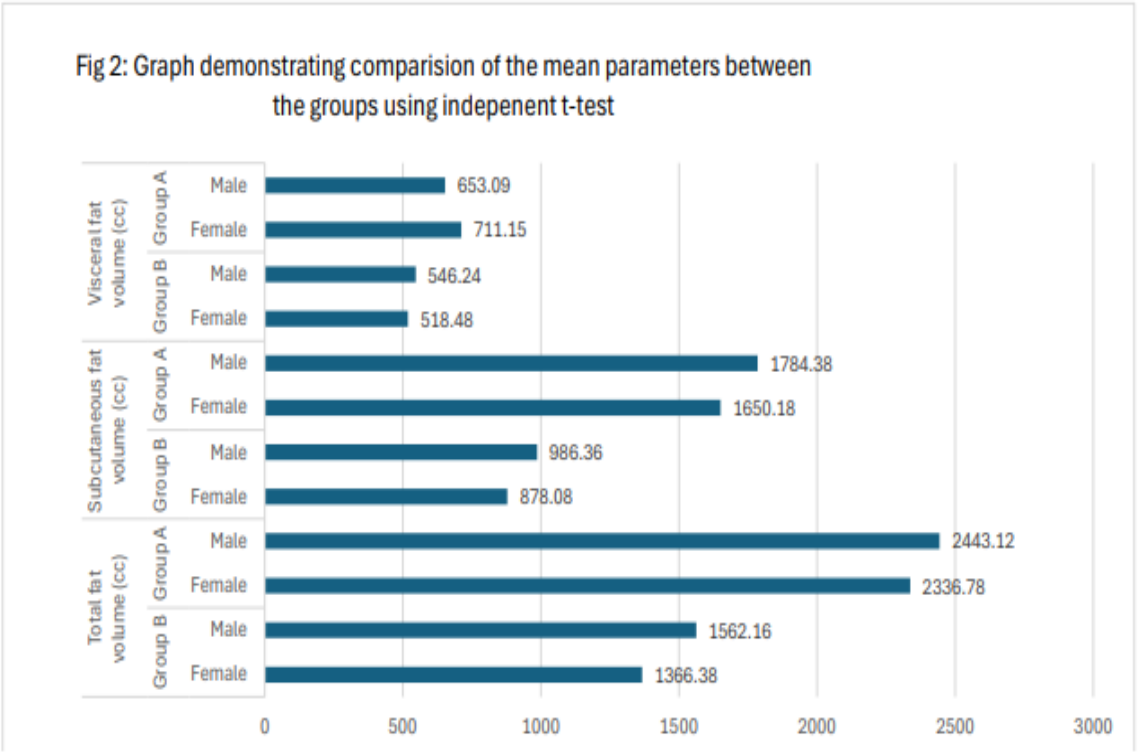

Figure 4:

Results

Approximately 112 cases who met the inclusion criteria were included in the study. Using CT/CECT scans of the abdomen and pelvis, we assessed the relationship between visceral fat volume (VFV), subcutaneous fat volume (SVF), and total abdominal fat volume and metabolic syndrome. Compared to Group B, which had a mean age of 50.12 ± 16.30 years, Group A had a mean age of 60.91 ± 12.23 years.

The mean difference between the groups was compared using an independent sample t-test, which revealed a statistically significant difference between the groups ($p = 0.001$). In the sample that

was gathered, there was a general male predominance (n = 69; 61.6%) compared to females (n = 43; 38.4%). When the chi^2 test was used to determine the relationship with gender, no statistically significant correlation was found between gender and the test outcomes. Group B had a slightly higher mean height (1.67 ± 0.09 m), but Group A had a higher mean weight and BMI (71.79 ± 10.43 kg and 27.18 ± 3.52 kg/m2, respectively). An independent sample t-test ($p < 0.05$) revealed no statistically significant difference between the groups, though (Table 1).

Group A was shown to have larger VFV, SFV, and total fat volume (TFV) (681.12 ± 92.58 cc, 1717.28 ± 285 cc, and 2389.85 ± 290.23 cc, respectively). The mean difference in visceral fat volume, subcutaneous fat volume, and total fat volume between the groups was compared using an independent sample t-test. A statistically significant difference ($p = 0.001$) was found between the groups by independent sample t-test (Table 2 and Figure 2).

Group B showed a greater visceral fat volume (546.24 ± 106.45 cc) in males, while Group A showed a higher visceral fat volume (711.15 ± 85.93 cc) in females. Males in both groups had greater subcutaneous fat volumes (1784.38 ± 304.23 cc in Group A and 986.36 ± 236.56 cc in Group B). The total volume was higher in males in both Group A and Group B. In Group A, the total volume was 2443.12 ± 318.56 cc, whereas in Group B, it was 1562.16 ± 325.12 cc.

The mean difference in visceral fat volume, subcutaneous fat volume, and total volume within the groups between genders was compared using an independent sample t-test. Regarding visceral fat volume, an independent sample t-test indicated a statistically significant difference between the genders in Group A. For both males and females, Group A had higher levels of visceral fat, subcutaneous fat, and total fat volume.

Discussion

A person has metabolic syndrome if three or more of the following five criteria are met: blood pressure over 130/85 mmHg, fasting triglyceride level over 150 mg/dl, fasting high-density lipoprotein cholesterol level less than 40 mg/dl (men) or 50 mg/dl (women), and fasting blood sugar over 100 mg/dl, as defined by the National Cholesterol Education Program Adult Treatment Panel (NCEP ATP) III definition.

Abdominal obesity is the term used to describe a condition when there is an excessive accumulation of visceral fat around the abdomen to the point where it is likely to have a negative impact on health. Abdominal obesity has been directly linked to metabolic and vascular problems, Alzheimer's disease, and cardiovascular disease. There is a substantial correlation between type 2 diabetes, visceral and central abdominal fat, and waist circumference. Visceral fat, also known as organ fat or intra-abdominal fat, is found inside the peritoneal cavity, packed in between internal organs and the abdomen. This contrasts with subcutaneous fat, which is located beneath the skin, and intramuscular fat, which is found scattered throughout skeletal muscle. Visceral fat is composed of many adipose depots, including mesenteric, epididymal white adipose tissue, retroperitoneal, and perirenal fat.

Subcutaneous adipose tissue may have a protective effect on glucose metabolism, according to previous research [17, 18]. On the other hand, certain studies point to a connection between dangerous cardiometabolic risk factors, such diabetes, and subcutaneous fat accumulation [19, 20].

Visceral adipose tissue (VAT) and subcutaneous adipose tissue (SCAT) differ from one another in the abdominal cavity in morphological, cellular, molecular, physiological, clinical, and prognostic aspects [21].

Anatomically, the mesentery and omentum contain the majority of VAT. VAT has a higher proportion of big adipocytes, is more cellular, vascular, and innervated than SCAT, has a lesser capacity to differentiate into preadipocytes, and contains more immune and inflammatory cells [21].

A total of 112 study participants were split into two groups for the current cross-sectional investigation: patients with metabolic syndrome (n = 53) and patients without metabolic syndrome (n = 59). They were assessed for the relationship between metabolic syndrome and the volume of visceral, subcutaneous, and total abdominal-pelvic fat on CT.

Although waist circumference and body mass index (BMI), which are frequently used as markers for predicting metabolic risk, are effective and practical tools, they differ greatly depending on the person's body frame size and offer little to no information about the relative distribution of body fat, particularly visceral adiposity [22, 23].

Certainly, there were some drawbacks to utilizing BMI and waist circumference as a proxy for metabolic and cardiovascular risks. It may not be appropriate to use waist circumference as an index to diagnose metabolic syndrome, especially in individuals with normal waist circumference and BMI who also have metabolic risk factors. For these reasons, measuring the body's visceral adipose tissue precisely may not be necessary if visceral fat area (VFA) is used instead [24]. In our investigation, we found that individuals with metabolic syndrome had greater visceral fat volume, subcutaneous fat volume, and total fat volume—681.12 ± 92.59 cm3, 1717.28 ± 285.00 cm3, and 2389.95 ± 290.23 cm3, respectively. Similarly, the visceral fat volume was

6495 ± 2069 cm3 for men and 4964 ± 1255 cm3 for women in the study by Jongjirasiri et al. [25], where the abdominal fat volumes were calculated between the uppermost part of the liver and the lowermost part of the pelvis or the level of the femoral head.

This difference was significant. The statistically significant mean subcutaneous volume was recorded as 9177 ± 2434 cm3 for males and 8631 ± 1656 cm3 for females. Visceral fat accumulation is often mentioned as a risk factor for cardiovascular diseases, such as diabetes mellitus. The fundamental feature of metabolic syndrome is visceral fat accumulation, which is directly linked to insulin resistance.

Visceral fat accumulation is commonly detected by a waist circumference of at least 85 cm for men and 90 cm for women on an abdominal CT scan at the umbilical level, which equates to a VFA of 100 cm2 [26]. In a longitudinal research evaluating the optimal cut-off value of VFA for type 2 diabetes prediction in 13,004 Koreans, men's levels were found to be 118.8 cm2, while women's values were found to be 82.6 cm2 [27].Patients with incident diabetes who also had metabolic syndrome had a baseline intra-abdominal fat area (IFA) of 102.7 cm2, compared to 74.3 cm2 for those without incident diabetes, according to a different 10-year longitudinal research.

Furthermore, a 1-SD increase in IFA was associated with a 1.65-fold increase in the chance of developing diabetes over a 10-year period after adjusting for the identified components [28]. The measured VFV, SFV, and TFV in the current investigation demonstrated a substantial difference between individuals with metabolic syndrome and those without it, as well as between the two genders.

The main result of this study was the robust and positive significant association between VFV in both genders and groups. Previous research has indicated that there may be substantial gender relationships between VFV, SFV, and metabolic syndrome [29–31]. In our investigation, we discovered a strong association between the metabolic syndrome and VFV in female patients.

Although the exact explanation of gender differences is unknown, it may be connected to the fact that women have been shown to have higher levels of hepatic free fatty acid delivery than men due to lipolysis from VFV [32]. Diabetes and central obesity are well acknowledged to be connected. There was no association between BMI and VFV, SFV, or TFV in the current investigation.

In a 10-year longitudinal research on the development of the disease, an increase of 1 SD in the intraabdominal fat region increased the risk of type 2 diabetes up to 1.65-fold; however, changes in body weight were unrelated to type 2 diabetes risk (odds ratio, 0.95; 95% CI: 0.66-1.35) [28]. An increase in visceral fat in the L2 to L3 region (measured using CT) increased the risk of developing diabetes by 1.48 times, according to another longitudinal cohort study. Conversely, a decrease in subcutaneous fat did not increase the incidence of diabetes in either sex; these associations were only seen in males. Ryo et al. [37] demonstrated that a decrease in accumulated visceral fat (measured by CT) attained within a year correlates with a decrease in the number of metabolic risk factors (hypertension, dyslipidemia, and hyperglycemia)[33,39] and an increase in serum adiponectin levels [40].

These findings were supported by the VACATION-J study [33–36] and the Amagasaki Visceral Fat study [37, 38]. A 4-year follow-up of cardiovascular events in 3228 employees (men 2486, women 742) using a risk factor-focused "Hokenshido" program revealed that the cumulative incidence of cardiovascular events was significantly lower in subjects with reduced visceral fat (20.7 ± 16.1 cm2) than in those with increased visceral fat (12.7 ± 14.6 cm2) ($p = 0.0049$) [41]. We found that individuals with metabolic syndrome had higher mean VFV, SFV, and TFV values in relation to hypertension, diabetes, and dyslipidemia than did the control group.

The diagnostic value of VFV was higher in women than in men when it came to predicting various metabolic risk variables in patients with metabolic syndrome; likewise, the diagnostic value of SFV and total abdominopelvic fat volume was higher in males in both groups. It's unknown what mechanism underlies this sex-specific outcome. It will take more research to clarify the causality of this discovery. To the best of our knowledge, no other research has demonstrated the value of VFV, SFV, and total abdominopelvic volume as markers for predicting metabolic risk factors in individuals of both sexes, independent of age and body mass index.

Conclusions

It has not been investigated if abdomen CT, a commonly used imaging modality, may be used to assess the risk of developing metabolic syndrome. BMI is not a reliable indicator of metabolic syndrome risk; instead, CT is a more precise way to measure visceral, subcutaneous, and total fat volume. Thus, the radiologist and the physician can collaborate to detect and treat this illness in an early and effective manner.

Authors' contributions:

Dr Babhita Raj Jayaraj - conceptualization, data curation, investigation, methodology, project administration, visualization, writing—original draft, writing—review and editing; Dr Puneet Shirbur -conceptualization, methodology, writing—

original draft, writing—review and editing; Dr Valambige mudalagirigowda puttaraju - conceptualization, visualization, supervision, writing—original draft. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work. All authors have read and agreed to the published version of the manuscript**.**

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