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REVIEW

Central Obesity: An Emerging Player in Cardiac Remodelling and Dysfunction

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Abnormal or excessive fat accumulation is defined as obesity. The prevalence of obesity has risen worldwide in the last years. Obesity increases cardiovascular disease risk, affecting cardiac and vascular systems. Accordingly, the health burden related to obesity has been increased. Notably, even individuals with normal body weight can present with excessive accumulation of visceral fat, also known as central obesity. Population-based studies demonstrated associations between central obesity measures, including waist circumference, waist-to-hip ratio, and visceral adipose tissue, and adverse cardiovascular events and increased all-cause mortality. It has been shown that central obesity induces cardiac remodelling and dysfunction. Moreover, central obesity measures proved to be more reliable predictors of cardiac remodelling and dysfunction than traditional obesity measures such as body mass index. This review presents recent evidence of the detrimental effects of central obesity on cardiac function and structure.

Keywords Central obesity • Waist circumference • Waist-to-hip ratio • Cardiac remodelling

Introduction

Obesity, defined as abnormal or excessive fat accumulation, has reached epidemic proportions worldwide, with prevalence rates doubling since 1990 and statistical models projecting 60% of adults worldwide will be overweight or obese by 2050 [1–3]. This public health challenge affects high-income nations disproportionately, where systemic limitations in policy and health care infrastructure have contributed to its progression [2,3]. The economic influence is substantial, mainly attributable to cardiovascular disease, which remains the predominant cause of mortality in this population, responsible for more than two-thirds of obesity-related deaths [4,5]. Obesity is connected to cardiovascular diseases through various pathways, which include direct physiological effects and indirect effects mediated by additional risk factors such as diabetes mellitus, hypertension, dyslipidaemia, and systemic inflammation [6,7]. Obesity can affect cardiac physiology directly by causing hemodynamic alterations characterised by increased blood volume and inducing inflammatory and metabolic changes, all of which lead to cardiac remodelling and dysfunction [8]. Obesity is also associated with metabolic and inflammatory changes that contribute to the cardiac remodelling, including activation of the renin-angiotensin-aldosterone and sympathetic nervous systems, hyperleptinemia due to leptin resistance, low circulating adiponectin levels, insulin resistance with hyperinsulinemia, and potential cardiac lipotoxicity [9].

According to recent data, increased visceral fat accumulation, also known as central obesity, is more closely linked to various metabolic disturbances and cardiovascular

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diseases than general obesity [10–14]. Although central and general obesity are detrimental, recent findings indicate that visceral adipose tissue (VAT) accumulation carries a greater risk for developing diverse pathological conditions, including cardiovascular and metabolic disorders [10]. It has been shown that greater accumulation of abdominal fat tissue is associated with a higher prevalence of coronary artery heart disease [11], hypertension [12], type 2 diabetes [13], and hypertriglyceridemia [14]. In this review, we summarise recent studies on the effect of central obesity on cardiovascular morbidity and mortality as well as specific effects of central obesity on cardiac remodelling and dysfunction in individuals with central obesity. In the literature, central adiposity is also referred to as visceral or abdominal obesity; however, for simplicity, we will use the term central obesity throughout this manuscript, even if the original articles refer to visceral or abdominal obesity.

Obesity Assessment

The widely used measure of obesity is body mass index (BMI), which is calculated using the formula: BMI = weight (kg) ÷ height $(m)^2$. Bioelectrical impedance analysis (BIA) is another method for estimating body composition by measuring electrical conductance of body tissues [15]. This technique relies on the principle that different biological tissues exhibit distinct electrical conductivity, allowing the estimation of fat mass, fat-free mass, and total body water. BIA is valued for its speed, non-invasiveness, and affordability, making it suitable for routine assessments in clinical and research settings. However, its accuracy can substantially vary due to factors such as hydration status and the integrity of cellular membranes, which can lead to inconsistent results depending on the physiological state of the individual being assessed [16,17]. The main disadvantage of using BMI and BIA is that they cannot differentiate between fat and lean mass and do not account for variations in body fat distribution [18].

Central Obesity Assessment

Accumulating evidence suggests that even individuals with normal BMI might present with central obesity, emphasising that BMI measurements alone cannot identify health risks associated with abdominal fat accumulation [19,20]. Central obesity can be assessed by various methods, each presenting distinct advantages and limitations [21–23]. Waist circumference (WC) and waist-to-hip ratio (WHR) are well-established and widely used measures of central obesity. WC serves as a simple and cost-effective metric. It is measured around the abdomen at the level of the iliac crest. This measurement is quick to obtain and reliably identifies individuals at risk for cardiovascular and metabolic conditions. Specifically, a WC of 94 cm or greater in men and 80 cm or greater in women correlates with increased risks of adverse cardiovascular outcomes [24]. However, its accuracy in reflecting fat distribution may vary across different populations [25,26].

WHR provides a comparative measure of body fat distribution, calculated by dividing WC by hip circumference. This metric shows the strongest and most consistent association with mortality in the general population [27] but requires precise measurements of WC and hip circumference, which can be challenging [28–30].

Recently, various imaging techniques have been used to characterise and phenotype body fat distribution. These techniques demonstrate strong correlations with simple measures of central obesity, including WC and WHR, and offer better characterisation of body fat distribution.

Ultrasound techniques, widely available in clinical settings, serve as a complementary method for central obesity assessment, supplementing traditional anthropometric measures when other imaging modalities are unavailable. These techniques provide precise measurements of visceral fat distribution in individuals with obesity in the abdominal region [31,32]. Measurements conducted at specific abdominal sites enable direct assessments of subcutaneous as well as intraperitoneal fat distributions, including mesenteric, perirenal, preperitoneal, and intraperitoneal fat deposits, that exhibit strong correlations with established anthropometric indicators, including BMI and WC, as well as with diverse health risks [33–35], validating ultrasound as an essential complementary instrument in central obesity assessment [32]. Moreover, ultrasound demonstrates higher precision for quantification of fat thickness and distribution than anthropometric measures. This enhanced accuracy proves particularly valuable in research contexts and for monitoring body composition changes over time [36]. However, there are no internationally established cut-off values for those ultrasound-based variables to accurately identify and diagnose central obesity in various populations and conditions, making such standardisation requiring future studies.

Computed tomography (CT) provides cross-sectional images of the body, enabling precise measurement of VAT [23]. Recognised as the gold standard for the quantitative assessment of VAT due to its high accuracy and reproducibility in clinical settings, CT effectively differentiate VAT and fat from other tissues, using specific Hounsfield unit ranges [23,37,38]. Despite its advantages, CT has substantial limitations, including high costs and radiation exposure, which can make its routine use for screening impractical.

Alternative imaging techniques, such as magnetic resonance imaging (MRI), have recently emerged as a pivotal non-invasive imaging modality for assessment of visceral adiposity, providing detailed insights into body fat distribution and characteristics [39]. MRI produces high-resolution, three-dimensional images that enable precise differentiation between VAT and subcutaneous adipose tissue [39,40]. MRI demonstrates similarity accuracy with CT in measuring VAT and avoids radiation exposure [37,41,42]. Although MRI is generally safer, it can be less accessible and more expensive than CT [23,38].

Several studies have demonstrated that increased VAT, as measured by imaging modalities, surpassing certain thresholds correlates with various health risks [43]. For instance, a study indicates that a VAT area≥106 cm^2 in women is associated with increased metabolic risk factors for coronary heart disease [44]. Additionally, VAT thresholds of 104.3 cm^2 for men and 94.1 cm^2 for women have been linked to metabolic syndrome in individuals with ischaemic stroke [45]. Although central obesity has been defined within the Japanese population as VAT≥100 cm^2 [46]. However, the some available studies investigating the effects of central obesity on cardiac remodelling have used VAT cut-off values ≥130 cm^2 [47,48], whereas others have used VAT measurement to assess central obesity without adhering to specific cut-off values [49,50].

In summary, considerable challenges persist in achieving standardisation of measurement methodologies across imaging modalities and protocols with consideration of gender- and population-specific characteristics. Evidence suggest that MRI and CT can be considered as gold standard techniques for the quantification of VAT, demonstrating associations with a wide range of metabolic and cardiovascular risk factors. Nevertheless, future studies should prioritise the standardisation of measurement protocols, the advancement of more accessible estimation techniques, and the identification and optimisation of clinical thresholds tailored to specific populations and genders.

Effects of Central Obesity on Morbidity and Mortality

Compelling evidence indicates that central obesity poses a higher risk of morbidity and mortality than general obesity measured by BMI (Table 1). Central obesity measures, specifically, WC and WHR, demonstrate stronger correlations with adverse health outcomes than BMI. A comprehensive meta-analysis, including 72 prospective cohort studies with a total of 2,528,297 participants, revealed that these central obesity measures are associated with an increased risk of all-cause mortality, even after adjusting for BMI [51]. A prospective, longitudinal cohort study established VAT as a primary predictor of heart failure specifically in Black but not in White populations [50]. Moreover, a large-scale investigation of 20,298 participants demonstrated central obesity increased cardiovascular disease risk by 33% when adjusted for demographics, smoking, and alcohol consumption, although this correlation diminished after metabolic status adjustment [52].

An analysis of 156,000 post-menopausal women indicated that having normal weight combined with central obesity was associated with a higher likelihood of all-cause mortality and cardiovascular disease than individuals with normal weight and no central obesity [53]. Moreover, a retrospective study of 1,697,903 subjects showed that individuals with normal weight with central obesity exhibited increased risks of heart failure, atrial fibrillation, and angina pectoris [54]. Furthermore, a stratified multistage probability study of 15,184 subjects revealed that individuals with normal weight with central obesity showed higher total and cardiovascular mortality risks than those classified as overweight or obese by BMI alone [55].

In patients with type 2 diabetes mellitus, increases in WC were associated with heart failure onset and increased all-cause mortality [56]. Additionally, a prospective cohort study reported that high WC combined with diabetes increased cardiovascular death risk by 2.3 times [57]. A study with 3,320 individuals with heart failure with preserved ejection fraction (HFpEF) found that central obesity was correlated with an increased risk of all-cause mortality, particularly, in men [58].

Population-based studies have conclusively established central obesity as a major determinant of cardiovascular outcomes and mortality (Table 1). A prospective population-based study of 1,346 male subjects found a 9.8 cm increase in WC increased coronary event risk by 24.2% [59]. Moreover, men with WC exceeding 90.0 cm experienced double the risk compared with those with WC below 83.5 cm [59]. Secondary analysis of the Heart Outcomes Prevention Evaluation (HOPE) study demonstrated that increases in WC were associated with a 23% higher myocardial infarction risk, 38% higher heart failure risk, and 17% higher total mortality [60]. Additionally, a prospective, longitudinal cohort study identified WC as a predictor of incident heart failure, with WC and body fat percentage emerging as significant predictors [50]. Further evidence from a prospective cohort study showed that each standard deviation–increase in WC raised heart failure risk by 14% after adjusting for BMI and other confounders [61]. Moreover, an investigation of 8,202 individuals revealed increased WC was associated with increased hospital admission rates over 18 years of follow-up [62]. Higher WC was also associated with increased all-cause and cardiovascular mortality risk in men and women, as was demonstrated in a large cohort study of 19,735 subjects [63].

Taken together, the central obesity marker, WC, is a significant predictor of adverse cardiovascular outcomes and mortality, as supported by several population-based and prospective studies. These studies consistently show that increased WC is associated with higher risks of coronary events, myocardial infarction, heart failure, and overall mortality.

Another measure of central obesity, WHR, also serves as a powerful predictor of cardiovascular outcomes and mortality. Furthermore, a prospective, longitudinal cohort study of 2,435 participants identified baseline WHR as a predictor of incident heart failure in men but not women [50]. Additionally, a prospective cohort study that followed 516 female participants for 7 years demonstrated that high WHR rather than WC increased cardiovascular event risk [64].

A prospective population-based study of 1,346 male subjects demonstrated a 21.3% increase in coronary event risk with each 0.06 increase in WHR, whereas a WHR exceeding 0.91 tripled this risk [59]. Secondary analysis of the HOPE study revealed women with each 0.01-WHR increase above

Table 1 Summary of the community-based studies assessing the associations of central obesity with cardiovascular outcome and mortality.

Study	Study design	Study population	Assessment of central obesity	Key findings of the study
Lakka et al. 2002 [59]	Prospective population-based study	Male subjects: n=1,346; mean age 51.6±5.9 years	Assessed central obesity markers: Men with WHR: <0.91 (n=314), 0.91–0.94 (n=33), 0.95–0.98 (n=35), >0.98 (n=43) Men with WC: <83.5 cm (n=20), 84–89.5 cm (n=27), 90–95.5 cm (n=37), >95.5 cm (n=39)	• ↑ WHR by 0.06 → ↑ coronary event risk by 21.3% • ↑ WHR>0.91 → ~3×coronary event risk • ↑ WC by 9.8 cm → ↑ coronary event risk by 24.2% • ↑ WC≥90.0 cm (men) → ~2×coronary event risk vs WC<83.5 cm
Dagenais et al. 2005 [60]	Secondary analysis of the HOPE study with a 5-year follow-up period	n=8,802, mean age 66 years, (Men n=6,620; Women n=2,182)	Assessed central obesity markers: WC: Women: <87 cm, 87–98 cm, ≥98 cm. Men: <95 cm, 95–103 cm, ≥103 cm. WHR: Women: <0.83, 0.83–0.90, ≥0.90. Men: <0.93, 0.93–0.97, ≥0.97	• ↑ WC → ↑ risk of MI (23%), HF (38%), total mortality (17%) • ↑ WHR by 0.01 (>0.83) (women) → ↑ risk: CVD death (4%), MI (4%), HF (5%) • ↑ WHR → ↑ risk: CVD death (24%), MI (20%), total mortality (32%) • ↑ WHR≥0.90 (women) → 2×risk of CV death and HF, ~2×risk of MI, total mortality • ↑ WHR (women) predicts CVD events (excluding stroke)
Nicklas et al. 2006 [50]	Prospective, longitudinal cohort study (Health, Aging and Body Composition study)	n=2,435, mean age 73.6 years, (Men n=1,081; Women n=1,354)	Assessed central obesity markers: WC>102 cm (Men), >88 cm (Women). VAT measured by CT	• ↑WC & %body fat → predict HF • ↑VAT → predicts HF in blacks, not whites • ↑WHR (men not in women) → ↑incident HF
Cabrera et al. 2007 [64]	Prospective cohort study with a 7-yr follow-up period	Female subjects: n=516; mean age 70.9 years	Assessed central obesity markers: WC quartiles: 63–84cm, 85–90 cm, 91–96 cm, and 97–130 cm. WHR quartiles: 0.70–0.88, 0.89–0.92, 0.93–0.98, and 0.99–1.12	• ↑ WHR → ↑ cardiovascular event risk • ↑ WC → no significant effect on cardiovascular event risk
Ammar et al. 2008 [65]	Cross-sectional, population-based cohort study (average follow-up 5.5 years)	n=2,042, (Men n=982; Women n=1,052)	Central obesity: WHR≥0.9 (Men), ≥0.85 (Women). Obesity: BMI≥30 kg/m^2	• ↑ WC by 1 SD → ↑ LV diastolic dysfunction odds by 1.36× • ↑ WHR → ↓ LVEF • ↑ WHR by 1 SD → ↑ LV diastolic dysfunction odds by 1.55× • ↑ WHR by 1 unit → 23.59×all-cause mortality risk

Table 1. **(continued).**

Study	Study design	Study population	Assessment of central obesity	Key findings of the study
Wildman et al. 2012 [52]	Pooled analysis of data from three large cohorts: Framingham Offspring Study (FOS), Atherosclerosis Risk in Communities Study (ARIC), and CHS with average follow-up of 8.3 years	n=20,298, ≥45 years	Assessed central obesity markers: WC>102 cm (Men), >88 cm (Women)	• ↑ WC → ↑ total CVD risk by 33% (adjusted for demographics, smoking, alcohol) • This association not significant after adjusting for metabolic status
Djoussé et al. 2012 [61]	Prospective cohort study using data from the CHS from 1989 to 2007	n=4,861, (Men n=2,063, mean age 73.0±5.6 years; Women n=2,798, mean age 72.3±5.4 years)	Assessed central obesity markers: WC≤91, 91.1–97.2, 97.3–104, and >104 cm (Men) and ≤82, 82.1–91.6, 91.7–101.1, and >101.1 cm (Women)	• ↑ WC by 1 SD → ↑ HF risk by 14% (adjusted for BMI & covariates) • ↑ WHR by 1 SD → ↑ incident HF risk (adjusted for BMI and covariates) • ↑ WC by 1 SD→ ↑ HF risk with ↓ LVEF by 28% (no ↑ in risk with normal LVEF) • ↑ BMI by 1 SD→ ↑ incident HF risk by 22% (non-significant after WC adjustment)
Sahakyan et al. 2015 [55]	Stratified multistage probability design study	n=15,184, (Men n=7,249; Women n=7,935; mean age 45 years)	Assessed central obesity markers: WC>88 cm (Women), >102 cm (Men); WHR≥0.85 (Women), ≥0.90 (Men)	• Normal BMI + central obesity (men) → ↑ total mortality risk vs no central obesity • Normal BMI + central obesity (men) → ∼2× ↑ total mortality risk vs overweight/obese without central obesity • Normal BMI + central obesity (women) → ↑ total mortality risk vs no central obesity • Normal BMI + central obesity (women) → ↑ total mortality risk vs obese (by BMI) women • Normal BMI + central obesity (men) → ↑ cardiovascular mortality risk vs no central obesity • Normal BMI + central obesity (women) → ∼2× ↑ cardiovascular mortality risk • ↑ WHR (both sexes) → ↑ mortality risk, cardiovascular mortality risk

Table 1. (continued).

Study	Study design	Study population	Assessment of central obesity	Key findings of the study
Ueno et al. 2022 [54]	Retrospective observational study using the JMDC Claims Database in Japan (2005 to April 2020).	n=1,697,903; aged 40–75 years, (n=872,578 Men [51.4%]; n=825,325 Women [48.6%])	Assessed central obesity markers: WC≥90 cm (men) or ≥80 cm (women). Normal-weight central obesity: normal weight (BMI: 18.5–23.0 kg/m^2) with central obesity.	• Normal-weight with ↑ WC → slightly ↑ risk of HF, atrial fibrillation, angina pectoris.
Li et al. 2022 [57]	Prospective cohort study	n=1,521; mean age 70.96 years, (Men n=900; Women n=621)	Assessed central obesity markers: WC classification: <82 cm, 82–94 cm, and >94 cm	• WC>94 cm+diabetes → ~2.3×risk of cardiovascular death • WC>94 cm (adjusted for confounders) → ↑ risk of cardiovascular death • WC>94 cm + diabetes (adjusted for confounders) → ↑ risk of cardiovascular death
Liu et al. 2023 [63]	Cohort study	n=19,735, (men n=9,472, mean age 46.20 years; Women n=10,263, mean age 44.69 years)	Assessed central obesity markers: WC	· ↑ WC (both sexes) → ↑ all-cause mortality risk · ↑ WC (both sexes) → ↑ CVD mortality risk
Ramezankhani et al. 2023 [62]	Population-based prospective investigation	n=8,202, (Men n=3,727, mean age 48.1 years; Women n=4,475, mean age 46.3 years)	Assessed central obesity markers: normal WC (<95 cm) and high WC (≥95 cm)	• High WC (men) → ↑ hospital admissions by 18% • High WC (women) → ↑ hospital admissions by 30%

Abbreviations: WHR, waist-to-hip ratio; WC, waist circumference; HOPE, Heart Outcomes Prevention Evaluation; MI, myocardial infarction; HF, heart failure; CVD, cardiovascular disease; CV, cardiovascular; VAT, visceral adipose tissue; CT, computed tomography; BMI, body mass index; SD, standard deviation; CHS, cardiovascular health study; LVEF, left ventricular ejection fraction.

0.83 faced a 4% higher risk for cardiovascular death, myocardial infarction, and heart failure [60]. Moreover, this study showed that women with WHR of 0.90 or higher experienced doubled risks of cardiovascular death and heart failure, along with nearly doubled risks of myocardial infarction and total mortality [60]. A cross-sectional, population-based cohort study found that an increase in WHR was strongly associated with left ventricular (LV) diastolic dysfunction and predicted in all-cause mortality better than BMI did [65].

Taken together, WHR is a potent predictor of cardiovascular outcomes and mortality. Studies have consistently shown that increases in WHR are associated with significantly higher risks of coronary events, myocardial infarction, heart failure, and all-cause mortality in men and women, often exceeding the predictive value of other measures such as BMI.

Effects of Central Obesity on the Heart

Several studies have demonstrated that central obesity significantly contributes to the development and severity of cardiac remodelling and dysfunction. Studies have employed techniques, such as echocardiography and MRI, to assess the specific effects of central obesity on cardiac structure and function, including the development of heart failure. Studies

support that central obesity markers, including WC, WHR, and VAT, are more closely associated with cardiac remodelling and dysfunction than BMI, highlighting the substantial effect of central obesity on cardiac structure (Table 2). This section discusses the specific effects of central obesity first on cardiac remodelling and then on cardiac function, including its effects on the atrium, and examines the mechanisms by which central obesity influences these variables.

Central Obesity and Cardiac Remodelling

Obesity has been implicated in eccentric and concentric LV remodelling patterns. Eccentric remodelling patterns in obesity mainly originate from the pre-load–dependent mechanisms, resulting from increased blood volume as the heart adapts to perfuse the expanded adipose tissue volume [66–68]. Conversely, concentric remodelling occurs more frequently in individuals with obesity with hypertension, where increased afterload significantly contributes to the development of the concentric LV remodelling pattern [66,69]. Although concentric remodelling was previously considered the predominant form of LV remodelling in obesity [70,71], recent findings demonstrate a substantial prevalence of eccentric remodelling. A meta-analysis of 22 studies with 5,486 individuals with obesity revealed that in those with LV remodelling, 66% exhibited eccentric remodelling, whereas 34% displayed concentric LV remodelling [72]. The type of predominant cardiac remodelling pattern in patients with obesity depends on a number of factors such as obesity severity and duration and the presence of hypertension [49,66].

Studies have demonstrated closer association of central obesity markers, including WC, WHR, and VAT, with cardiac remodelling and dysfunction than BMI, highlighting the substantial effect of central obesity on cardiac structure. According to several prospective and cross-sectional studies increases in WC, WHR, and VAT independently correlated with LV remodelling, exhibiting a stronger association with LV mass, hypertrophy, and dilation than BMI [47,73–78]. Moreover, observational, cross-sectional studies using CT to analyse visceral fat distribution reported that patients with obesity with VAT$\geq$130 cm^2 presented greater LV wall thicknesses and LV mass than those with VAT$<$130 cm^2 [47,48]. Furthermore, a prospective cohort study of 229 subjects with suspected metabolic syndrome revealed a correlation between increased visceral fat area, assessed by BIA, and increased LV mass [79]. A longitudinal prospective cohort study showed that individuals with central obesity who gained weight over a 6-year follow-up period developed LV remodelling, characterised by a significant increase in the LV mass-to-volume ratio [80]. Finally, a two-sample Mendelian randomisation study established a causal association between WHR adjusted for BMI, reduced LV volume, and an increased LV mass-to-volume ratio [81].

Taken together, central obesity markers, such WC, WHR, and VAT, have a more significant association with cardiac remodelling, including LV mass, hypertrophy, and dilation, than BMI. Various studies, including prospective, cross-sectional, and Mendelian randomisation analyses, consistently show that increased central obesity is strongly associated with adverse cardiac structural changes.

Central Obesity and Cardiac Dysfunction

Obesity has been shown to adversely affect cardiac function, influenced by factors such as the duration of obesity and comorbidities such as diabetes mellitus and hypertension. Generally, cardiac dysfunction develops alongside cardiac remodelling in obesity, however, initial stages of cardiac remodelling may occur without evident signs of cardiac dysfunction due to compensatory mechanisms. Data indicate that obesity induces both systolic and diastolic LV dysfunction. Markers of central obesity correlate more strongly with LV diastolic and systolic dysfunction than traditional general obesity marker BMI.

Several studies demonstrated significant associations between central obesity markers, including WC, WHR, and VAT, and LV systolic dysfunction. Specifically, most studies have indicated that WC and WHR correlated with altered LV global longitudinal strain (LV-GLS), indicating altered LV systolic function. For instance, several studies have demonstrated that central obesity markers, such as WC, WHR, and VAT, correlated with altered LV-GLS [49,77,79,82,83]. Interestingly, a population-based cohort study revealed that high WHR correlated with lower LV-GLS across all BMI classification (normal, overweight, and obese) [77]. This finding indicates that central obesity, as measured by WHR, independently and more significantly affects LV systolic function than overall obesity measured by BMI [77].

Central obesity also affects LV diastolic function. Several studies demonstrated a significant association between central obesity markers, including WC, WHR, and VAT, and LV diastolic dysfunction. For instance, measures of central obesity correlated strongly with altered values of LV diastolic dysfunction metrics such as LV-E deceleration time, LV early diastolic velocity (LV-E′), LV E/A ratio, LV-E′/A′ ratio, LV-E/E′ ratio, and isovolumetric relaxation time in several studies [73–77,82,83]. Notably, most studies show that WC and WHR values remain associated with the development of LV diastolic dysfunction even after adjusting for other risk factors [65], highlighting the crucial role of central obesity in the development of LV diastolic dysfunction.

Additionally, individuals with obesity with VAT$\geq$130 cm^2 exhibit longer LV-E deceleration time values than those with VAT$<$130 cm^2 [48]. A prospective cross-sectional study identified VAT as independently linked to the onset of LV diastolic dysfunction [49]. In subjects suspected of having metabolic syndrome, BIA assessment of visceral fat area correlated with altered LV-E′ values [79], indicating presence of LV diastolic dysfunction. Finally, a longitudinal prospective cohort study with an average follow-up of 6 years showed that individuals with central obesity who gain weight experienced notable changes in LV-E′ from baseline to follow-up, indicating progression of LV diastolic dysfunction [80].

Table 2 Summary of the studies assessing the effects of central obesity on cardiac remodelling and function.

Study	Study design	Study population	Compared groups	Assessment of central obesity	Key findings
Morricone et al. 2002 [47]	Cross-sectional, observational study	Patients with obesity (n=28; mean age 43.2; men [n=7], women [n=21]) and healthy controls (n=18; mean age 45.8; men [n=4], women [n=14])	Patients with obesity (n=28; VAT<130 cm^2 [n=9], VAT≥130 cm^2 [n=19]) and control subjects (n=18).	Central obesity: VAT via CT≥130 cm^2. WC and WHR	• ↑ WC → ↑ IVSd • ↑ WHR → ↑ LVIDd • ↑ VAT → ↑ IVSd, LVPWTd, LVMI • VAT≥130 cm^2 → ↑ IVSd, LVPWTd, LVMI vs VAT<130 cm^2
Malavazos et al. 2007 [48]	Observational, cross-sectional study	Women with obesity (n=27; mean age 33.3) and control women (n=15; mean age 36.8)	Women with obesity (n=27; VAT<130 cm^2 [n=12], VAT>130 cm^2 [n=15], and control women [n=15]).	Central obesity: VAT via CT≥130 cm^2. WC and WHR	• VAT≥130 cm^2 → ↑ IVSd, LVPWd, LV-E-DT, MPI vs VAT<130 cm^2
Ammar et al. 2008 [65]	Cross-sectional population-based design with a 5-year prospective mortality follow-up	Subjects (n=2,042; mean age was 62 yrs (range 45-96); men [n=982] and women [n=1,052])	Men (n=982) and women (n=1,052)	Central obesity: WHR≥0.9 for men and ≥0.85 for women	• WHR → ↑ LVEF, LV diastolic dysfunction, LV dimensions, LV mass, LA volume index vs BMI • ↑ WHR → ↑ odds of HF even with general obesity • ↑ WHR → predicts ↑ all-cause mortality
Eschalier et al. 2014 [74]	Cross-sectional study	Abdominal obesity group (n=87; aged 55±6 yrs, 48 (55.2%) were female). Control group (n=53; aged 54±6 yrs, 29 (54.7%) were female)	Central obesity (n=87) and no abdominal obesity (n=53)	Central obesity: WC>94 cm in men and >80 cm in women	• ↑ WC, WHR → ↑ LVM, CRI (LVM/LVEDV) • ↑ WC → LV diastolic dysfunction (LV-E′<10 cm/s)
Share et al. 2015 [82]	Cross-sectional study	Women with abdominal obesity (n=39; aged 22.4±3.5 yrs) and women without abdominal obesity (n=33; aged 20.0±0.7 yrs)	Women with central (n=39) and women without central obesity (n=33)	Central obesity: WC≥80 cm	• Central obesity (women) → ↑ LA diameter, LV-E/E′, IVRT, DT • Central obesity (women) → ↓ LV-E, LV-E′, LV-S′, LV-LS, LV-LDSR

Table 2. (continued).

Study	Study design	Study population	Compared groups	Assessment of central obesity	Key findings
Son et al. 2016 [75]	Population-based prospective cohort study (KoGES-ARIRANG)	Healthy men (n=1,460; mean age 54.5±8.1 yrs)	The study population was divided into tertiles based on WC: first tertile (WC<82 cm; n=487), second tertile (WC 82–89 cm; n=464), and third tertile (WC≥89 cm; n=509).	Assessed central obesity markers: WC tertiles: 82 cm and 89 cm	• ↑ WC → ↑ LA volume index, LVEDd, LVESd, LVMI • ↑ WC → LV diastolic dysfunction (↑ LV-E-DT, ↓ LV-E/A ratio) • Third tertile WC (men) → ↑ LA dilation vs first tertile WC • Third tertile WC → ↑ LV dilation, LV hypertrophy, LV diastolic dysfunction vs first tertile WC
Russo et al. 2016 [77]	Population-based cohort study from CABL study	Study participants (n=729; mean age 71.5±9.4 yrs, men [n=288] and women [n=441])	WHR: Normal WHR and High WHR. BMI: Normal (<25 kg/m^2), overweight (25–29.9 kg/m^2), and obese (≥30 kg/m^2)	Central obesity: WC>88 cm (women) and >102 cm (men); WHR≥0.85 (women) and ≥0.90 (men)	• ↑ WC, ↑ WHR → ↑ LV mass, ↑ LVM/LVEDV • ↑ WC, ↑ WHR → ↓ LV-E′, ↑ LV-E/E′ • ↑ WC, ↑ WHR → ↓ LV-GLS
Cho et al. 2019 [79]	Prospective cohort study	Subjects with suspected metabolic syndrome (n=229; mean age 56.4±4.5 yrs; men [n=115], women [n=114])	Subjects with high visceral fat area (n=113) and low visceral fat area (n=116)	Central obesity: WC≥90 cm (men), ≥80 cm (women); visceral fat area: measured by bioelectrical impedance (≥76 cm^2)	• ↑ Visceral fat area → ↑ LV mass index, ↓ LV-E′ lateral, and ↓ LV-GLS.
Mandry et al. 2021 [80]	Longitudinal, prospective cohort study (6.1±1.2-year follow-up)	Non-obese controls (n=58), subjects with abdominal obesity (n=75)	Non-obese controls (n=58); central obesity: with weight gain (n=16, >7% weight gain) and without weight gain (n=59)	Central obesity: WC>102 cm for men and >88 cm for women	• Central obesity + weight gain → ↑ LVM/LVEDV ratio, ↑ LV-E′ (baseline → follow-up)
Liu et al. 2022 [49]	Prospective, cross-sectional study	obesity group (BMI≥27.5 kg/m^2; n=48; mean age 32.6±8.9 yrs, male 54.2%), healthy control group (BMI<23 kg/m^2; n=25; mean age 33.3±10.4 yrs, male 48%)	Obesity group (n=48) healthy control group (n=25)	Assessed central obesity markers: WC, WHR, and VAT by dual X-ray absorptiometry	↑ WC, WHR → ↑ LV max myocardial wall thickness ↑ WHR → ↑ LV mass, LVM/LVEDV ↑ VAT → ↑ LV-GLS, LV LPDSR, LV CPDSR

Table 2. (continued).

Study	Study design	Study population	Compared groups	Assessment of central obesity	Key findings
Gao et al. 2023 [81]	Two-sample Mendelian randomisation	Exposure data: Individuals from the Genetic Investigation of Anthropometric Traits (GIANT) Consortium (n=224,459). Outcome data: Individuals from the UK Biobank Cardiovascular Magnetic Resonance substudy (n=16,923)	Exposure data: Individuals from the GIANT Consortium (n=224,459). Outcome data: Individuals from the UK Biobank Cardiovascular Magnetic Resonance substudy (n=16,923).	Assessed central obesity markers: WC adjusted for BMI (WCadjBMI), WHR adjusted for BMI (WHRadjBMI)	• ↑ genetically established WHRadjBMI → ↓ LVEDV, ↑ LVMVR • ↑ genetic liability to WHRadjBMI → ↓ LVESV (nominally significant), ↑ LVM (nominally significant)
Marttila et al. 2024 [78]	Prospective, consecutive, cross-sectional study from the METSIM (Metabolic Syndrome in Men) study	Central obesity group (n=29; age 57±4 yrs, only men), Control group (n=18; mean age 52±3 yrs, only men)	Central obesity group (n=29), Control group (n=18)	Central obesity: WC>100 cm and BMI<30 kg/m^2	• ↑ WC, WHR → ↑ LV maximal wall thickness

Abbreviations: BMI, body mass index; CPDSR, circumferential peak diastolic strain rate; CRI, cardiac remodelling index; DT, deceleration time; HF, heart failure; IVSd, diastolic interventricular septum thickness; IVRT, isovolumic relaxation time; LA, left atrium; LPDSR, longitudinal peak diastolic strain rate; LV, left ventricle; LV-LDSR, left ventricular longitudinal diastolic strain rate; LV-E, left ventricular early diastolic filling velocity; LV-E/A ratio, ratio of peak early to late ventricular filling velocities; LV-E′, left ventricular early diastolic tissue Doppler velocity; LV-E-DT, left ventricular early filling deceleration time; LV-GLS, left ventricular global longitudinal strain; LVEDd, left ventricular end-diastolic diameter; LVEDV, left ventricular end-diastolic volume; LVEF, left ventricular ejection fraction; LVESd, left ventricular end-systolic diameter; LVESV, left ventricular end-systolic volume; LVMI, left ventricular mass index; LVM, left ventricular mass; LVMVR, left ventricular mass/volume ratio; LV-LS, left ventricular longitudinal strain; LVPWd, left ventricular posterior wall diameter; LVPWTd, left ventricular posterior wall thickness diameter; MPI, myocardial performance index; VAT, visceral adipose tissue; WC, waist circumference; WCadjBMI, waist circumference adjusted for BMI; WHR, waist-to-hip ratio; WHRadjBMI, waist-to-hip ratio adjusted for BMI.

Central Obesity and Left Atrial Enlargement

Several studies implicated central obesity in dysfunction and remodelling of the left atrium (LA). Young, otherwise healthy women with central obesity exhibited subclinical cardiac dysfunction and larger LA dimensions compared with a control group [82]. In a population-based prospective cohort study of healthy men, an increase in WC correlated with a rise in LA volume [75]. Another population-based prospective cohort study revealed that an increase in WC was linked to a higher likelihood of LA dilatation [75]. In addition to conventional echocardiographic LA size measurements, recent technological advances in novel echocardiographic modalities have provided additional insights into the functional characteristics of the LA. Speckle tracking echocardiography has demonstrated that individuals with obesity exhibit significantly lower LA reservoir strain and conduit strain than control subjects, indicating reduced passive filling capacity [84]. These findings were subsequently consistent in younger cohorts, where subjects with obesity displayed lower LA reservoir strain than controls [85]. Notably, these LA abnormalities persisted after adjustment for age, sex, and comorbidities, suggesting intrinsic LA dysfunction independent of confounding factors in subjects with obesity [84]. However, no studies to date have analysed the direct effects of central obesity measures (WC, WHR, and VAT) on LA strain variables. Consequently, whether LA strain abnormalities are more pronounced in individuals with central obesity independent of BMI remains unestablished. Nevertheless, one study indicates this possibility by demonstrating that after weight loss, significant improvement in LA reservoir function correlated with visceral fat reduction [86], suggesting that visceral fat may exert direct effects on LA dysfunction.

Mechanisms of the Adverse Effects of Central Obesity on the Heart

The specific mechanisms through which central obesity adversely influences cardiac remodelling and dysfunction remain incompletely understood, although evidence implicates multifactorial interactions among hemodynamic, neurohormonal, inflammatory, and metabolic pathways.

Obesity broadly alters hemodynamic variables, including blood volume, heart rate, blood pressure, and cardiac filling pressures [87]. Obesity induces a state of relative volume overload that increases cardiac filling pressures, thereby contributing to structural and functional cardiac remodelling [88]. Indirect hemodynamic effects of obesity mediated by comorbidities, such as hypertension, obstructive sleep apnoea, sympathetic activation, and renin-angiotensin-aldosterone system dysregulation, further exacerbate cardiac dysfunction [68]. However, the distinct haemodynamic mechanisms of cardiac remodelling differentiating central obesity from general obesity remain underexplored and warrant further investigation. VAT functions as a metabolically active compartment that secretes diverse profibrotic and proinflammatory mediators with direct effects on different organs, including the heart. Visceral fat deposits can synthesise and release diverse proinflammatory and profibrotic factors [89–92]. Increased abdominal adiposity relative to total body weight correlates with increased circulating levels of C-reactive protein, interleukin-6, isoprostanes, osteopontin, and chemokine ligand 2 [79,89–92]. Gene expression analyses of human visceral fat biopsies demonstrate a proinflammatory transcriptional signature distinct from subcutaneous adipose tissue, suggesting tissue-specific metabolic dysregulation [93,94]. Most of those factors have been shown to promote cardiac dysfunction directly. For example, an experimental study has shown that ageing-associated increases in osteopontin expression within VAT increase plasma osteopontin levels, which directly impair cardiac function [92,95]. In individuals with obesity, WHR positively correlated with serum several inflammatory cytokines and their receptors, which correlated with echocardiographic cardiac remodelling variables [48], highlighting the critical role of proinflammatory factor regulation in central obesity.

Moreover, visceral fat also exhibits increased lipolytic activity, resulting in excessive free fatty acid (FFA) release [96]. Notably, central obesity variables, such as WC, WHR, and cardiac remodelling variables, correlate more strongly with lipid levels than BMI [97], suggesting the crucial role of abdominal fat on the levels of circulating lipids. In line with these findings, visceral fat was shown to have higher lipolysis rates than subcutaneous fat, potentially contributing to increased FFA release and metabolic disturbances [98]. Increased FFAs contribute to myocardial steatosis, insulin resistance, and metabolic dysfunction in cardiomyocytes [99]. These observations collectively implicate VAT as a critical mediator linking FFA excess, proinflammatory and profibrotic signalling in central obesity-related cardiac dysfunction. Nevertheless, the precise pathways regulating inflammatory, fibrotic, and metabolic crosstalk in central obesity-associated cardiac remodelling remain undefined.

Natriuretic peptides (NPs), including atrial natriuretic peptide and brain natriuretic peptide, exert physiological effects through three receptor subtypes: NPR-A, NPR-B, and NPR-C [100,101]. NPR-A and NPR-B activation stimulates the cyclic guanosine monophosphate pathway, whereas NPR-C facilitates NP clearance alongside neprilysin [100,101]. The myocardium synthesises NPs in response to pressure and volume overload [102], which play vital protective roles in cardiac physiology and pathologies by promoting vasodilation, natriuresis, and diuresis, as well as exerting antifibrotic and antiremodelling effects [103]. Despite increased NP levels in cardiovascular diseases, obesity paradoxically associates with reduced circulating NP concentrations, inversely correlating with BMI [104–108]. Proposed mechanisms include impaired NP synthesis due to insulin resistance and enhanced NP clearance via adipose tissue NPR-C upregulation [107,108]. Visceral fat accumulation correlates with increased NPR-C gene expression [109], and adipose tissue represents the second-largest NPR-C reservoir after the kidney [110]. For example, excess visceral fat increases the expression of clearance receptors for NPs on adipocytes, promoting their degradation and resulting in reduced circulating NP levels [104,111]. These findings suggest that VAT-mediated NP clearance may contribute to obesity-related NP deficiency. However, the mechanistic interplay between NPR-C overexpression, NP deficiency, and cardiac remodelling in central obesity remains unresolved.

Taken together, central obesity adversely affects cardiac function through complex interactions including hemodynamic alterations, inflammatory processes, and metabolic dysregulation. VAT actively secretes proinflammatory and profibrotic mediators that may directly impair cardiac function while also exhibiting increased lipolytic activity leading to excessive FFA release. Additionally, central obesity is associated with natriuretic peptide deficiency, potentially due to enhanced clearance via upregulated NPR-C receptors in VAT, although precise mechanisms linking these pathways remain incompletely understood.

The Effects of Weight Loss on Cardiac Reverse Remodelling

Many studies have investigated the effects of therapeutic weight loss strategies to mitigate adverse cardiac remodelling observed in obesity [112]. Several comprehensive meta-analyses indicate that bariatric surgery, recognised as the most effective intervention for substantial weight reduction in individuals with obesity, is associated with significant improvements in diverse cardiac functional and structural variables [113,114]. However, a systematic meta-analysis demonstrated that although LV variables improve post-surgery, right ventricular variables do not exhibit analogous improvements [114], suggesting differential ventricular responses to weight reduction. Interestingly, the cardiac benefits of body weight reduction via bariatric surgeries are evident within 3 months post-procedure [115] and persist for longer than 1 year [114]. Collectively, the consistent and substantial improvements in LV structural and functional variables observed across diverse studies

strongly support a causal relationship between significant weight loss induced by bariatric surgery and the reversal of obesity-related LV remodelling and dysfunction, with sustained benefits over extended periods. Nevertheless, the observed benefits may not be solely attributable to weight reduction. Improvements in metabolic and hemodynamic profiles also play crucial role in improvements of cardiac structural and functional variables in response to the obesity management [116]. Similarly, another study reported significant cardiac reverse remodelling after bariatric surgery independent of corresponding reductions in BMI [117]. These findings indicate that weight reduction strategies, particularly, bariatric surgery, improve LV variables through complex mechanisms potentially extending beyond simple mass reduction.

Pharmacological agents represent an expanding therapeutic classification for managing obesity and its associated cardiovascular risks [118,119]. Glucagon-like peptide-1 (GLP-1) receptor agonists (GLP-1 RAs) have emerged as a substantial therapeutic advance in managing obesity and related metabolic conditions. Specific GLP-1 RAs, such as semaglutide and liraglutide, have demonstrated marked efficacy in promoting weight loss, achieving body weight reductions of 15%–25% in patient cohorts with obesity over approximately 1 year [120]. A meta-analysis revealed that although GLP-1 RAs did not significantly reduce heart failure hospital admissions among patients with heart failure, they did improve LV diastolic function [121]. It is suggested that GLP-1 RAs exert their cardiac benefits via diverse mechanisms, including weight reduction, amelioration of metabolic alterations, and direct cardiac effects [122]. Furthermore, a recent meta-analysis showed that GLP-1 RAs significantly reduce VAT in adult populations with or without diabetes and non-alcoholic fatty liver disease [123]. However, studies specifically assessing the effects of GLP-1 RAs on central obesity variables, such as WC and WHR, in conjunction with detailed assessments of cardiac structure and function within populations characterised by central obesity, remain lacking, necessitating further investigation.

A notable limitation in the existing literature is the predominant reliance on BMI for obesity assessment. Consequently, studies specifically designed to assess interventions targeting central obesity markers, including WC, WHR, and VAT, are relatively scarce. Nonetheless, recent evidence indicates that strategies effective in reducing central obesity are associated with favourable cardiac outcomes. For example, one study demonstrated that specific types of bariatric procedures promoted substantial reductions in VAT concurrent with more significant LV reverse remodelling [124]. Moreover, numerous beneficial changes in LV structure and function appear to be maintained long-term after successful weight loss, particularly, after bariatric surgery associated with VAT reduction, which correlates with favourable cardiac effects [125]. These studies highlight the need for further research specifically assessing the effect of central obesity reduction on cardiac reverse remodelling.

Discussion

Central obesity represents a critical health problem currently under intense investigation due to its profound effects on cardiovascular outcomes, mortality, and cardiac remodelling and dysfunction (Table 1 and 2). This condition is defined by excessive fat accumulation in the abdominal region and presents distinct risks compared with general obesity [50,59,60]. Central obesity substantially increases the risk of cardiovascular disease (Table 1). Recent studies demonstrated that individuals with central obesity exhibited higher rates of hypertension, dyslipidaemia, and insulin resistance, all of which are significant risk factors for cardiovascular diseases [126,127]. Moreover, central obesity contributed to adverse cardiac remodelling, characterised by cardiac hypertrophy and dysfunction, ultimately leading to heart failure and other severe cardiovascular complications [81,128].

Several studies emphasise that central obesity, measured by WC or WHR, is an independent risk factor for cardiovascular diseases and related events [50,59,60]. In particular, central obesity has been connected to an increased risk of coronary heart disease [129], stroke [130], and heart failure [50,61]. Notably, central obesity is increasingly considered as a direct cause of HFpEF rather than merely a comorbid condition [81]. The prevalence of central obesity (77%) exceeds that of general obesity (62%) in patients with HFpEF [131]. In addition, presence of central obesity substantially increases prevalence of diabetes and dyslipidaemia in patients with HFpEF [131].

Several studies suggest that variables of central obesity serve as better indicators of cardiovascular outcomes than the general obesity marker BMI [60,65,75,77,81,132]. For example, some studies indicate that central obesity may be a stronger predictor of cardiovascular disease risk than overall obesity as measured by BMI [60,65,75,81]. WHR is a better discriminator of cardiovascular risk than BMI [77,132]. However, other studies suggest that BMI, WC, and WHR have similar strengths of association with cardiovascular diseases [133]. Moreover, some studies propose that the relationship between central obesity and cardiovascular disease is largely driven by the metabolic abnormalities that often accompany central obesity, such as hypertension, diabetes, and dyslipidaemia [52]. Although central obesity serves as a clinical indicator of potential metabolic problems, these metabolic abnormalities may be more critical prognostic indicators of cardiovascular disease risk than central obesity alone [52]. Nonetheless, other research indicates that central obesity independently increases cardiovascular disease risk, even when accounting for these factors [50].

Central obesity, even in individuals with normal weight and BMI, can have detrimental effects on cardiovascular outcomes. Several studies have demonstrated the risks associated with normal-weight central obesity, where individuals have a normal BMI but carry excess abdominal fat [55,134]. Normal-weight central obesity has been linked to an increased risk of heart failure and atrial fibrillation, even in

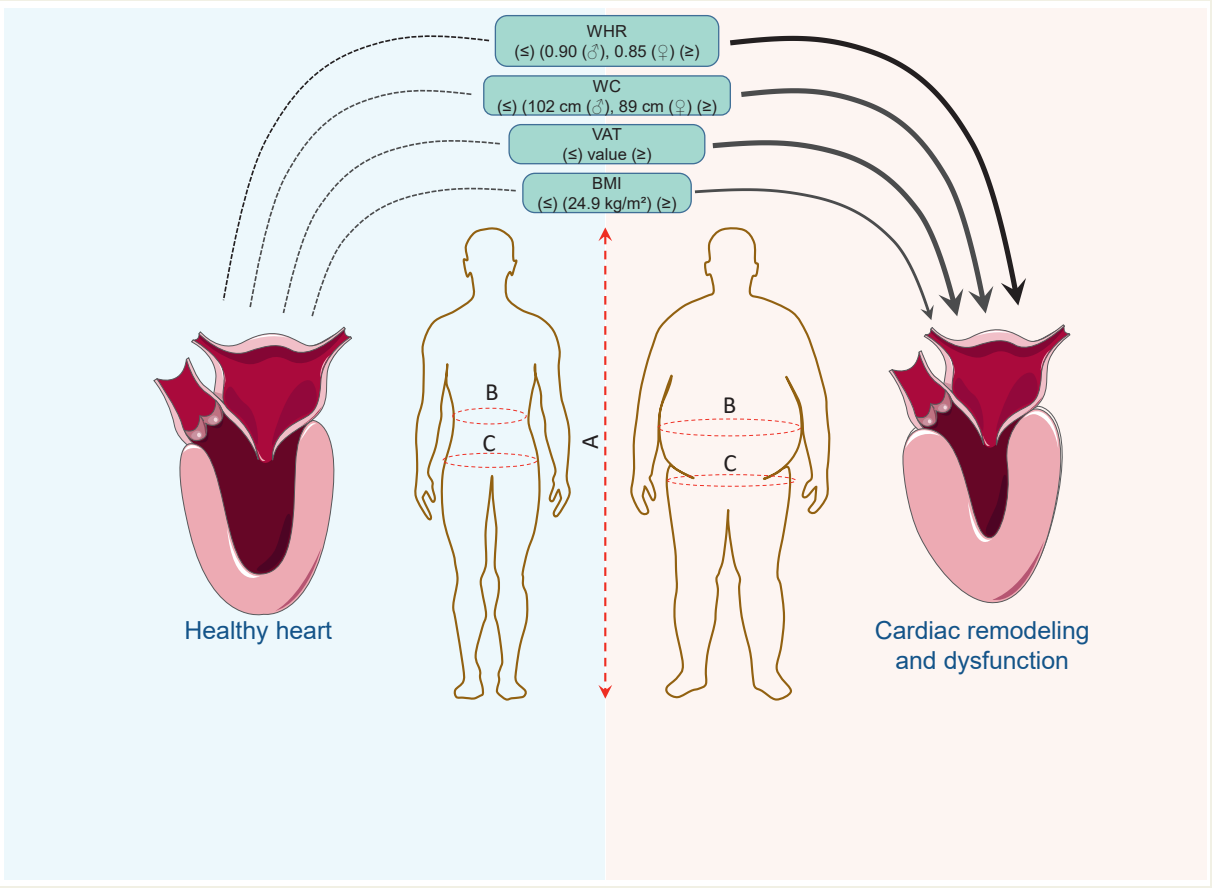

Figure Central obesity and cardiac remodelling. Numerous studies have demonstrated that markers of central obesity, such as WC, WHR, and VAT, exert more pronounced adverse effects on the heart than the general obesity marker, BMI. These adverse effects contribute to the development of cardiac remodelling and dysfunction. The measures of obesity are defined as follows: BMI is calculated as BW (in kilograms) divided by height (H) (in metres [A]); WC is measured as waist circumference (in centimetres [B]); WHR is measured by dividing WC (in centimetres [B]) by hip circumference (in centimetres [C]); and VAT represents the visceral adipose tissue area (in square centimetres [cm^2]), measured using imaging techniques such as CT, MRI, or BIA. → Indicates strong adverse effects on the heart when the values increased, whereas — represents neutral effects observed when the values remain low. Some components of the figure were adapted from the Servier Medical Art, provided by Servier and are licensed under a Creative Commons Attribution 3.0 Unported License (https://creativecommons.org/licenses/by/3.0/).
Abbreviations: WC, waist circumference; WHR, waist-to-hip ratio; VAT, visceral adipose tissue; BMI, body mass index; BW, body weight; CT, computed tomography; MRI, magnetic resonance imaging; BIA, bioelectrical impedance analysis.

those with a normal BMI [54]. Moreover, individuals with normal-weight central obesity have a higher risk of all-cause mortality than those with normal weight without central obesity [53,55]. These findings suggest that excess abdominal fat poses significant cardiovascular risks, regardless of overall weight status.

The distribution of body fat, including visceral versus subcutaneous fat and fat in the lower extremities, critically influences metabolic health [135]. Lower body, upper body subcutaneous, and visceral fat depots each exhibit unique characteristics in fatty acid metabolism. Prominence of these fat deposits significantly affects metabolic status and complications associated with obesity [135]. For example, studies indicate that adipose tissue in the legs and buttocks may improve glucose metabolism, whereas central fat distribution associates with altered metabolic status [98,136,137]. Moreover, increases in arm, calf, and thigh circumference correlate with reduced all-cause and cardiovascular disease mortality [63]. However, visceral fat accumulation remains a better indicator of adverse cardiovascular outcomes [138,139].

Central obesity significantly affects cardiovascular outcomes and mortality, partly due to its substantial effects on the heart. For example, central obesity is strongly correlated with increased risks of LV hypertrophy and adverse LV remodelling (Table 2). Furthermore, it is linked to impairments in LV systolic and diastolic functions. For instance, higher WC and WHR are linked to lower LV-GLS, indicating subclinical LV systolic dysfunction and altered LV diastolic

function (Table 2). Central obesity is also linked to left atrial dilatation (Table 2). In summary, central obesity is strongly linked to adverse cardiac remodelling characterised by LV hypertrophy and dysfunction. This relationship highlights the importance of addressing central fat accumulation in clinical settings to prevent cardiovascular complications associated with obesity.

Heterogeneity in body composition, fat distribution, and disease risk across ethnic populations necessitates ethnicity-specific cut-off values for WC, WHR, and imaging-based central obesity variables. The increased prevalence of central obesity and associated metabolic complications at lower BMI levels in Asian populations has necessitated the development of population-specific recommendations [140]. The International diabetes federation has established reduced WC thresholds for South Asian (90 cm), Chinese (90 cm), and Japanese (85 cm) men and for South Asian (70 cm), Chinese (74 cm), and Japanese (90 cm) women [141,142]. These variables are derived from the studies indicating that individuals from these ethnic backgrounds may exhibit increased cardiometabolic risk at WC measurements below standard European thresholds [143]. Furthermore, research conducted in the United States demonstrated that at equivalent levels of cardiometabolic risk, African American women exhibited larger WC than White women, suggesting variations in optimal threshold values [144]. However, the implications of these ethnic-specific differences in central obesity characteristics on cardiac structure and function across these populations remain unexplored and warrant future investigation.

Future Directions and Research Gaps

Recent studies demonstrate the substantial influence of central obesity on cardiovascular outcomes, mortality (Table 1), and cardiac function and structure (Table 2). However, several critical research gaps require attention in future studies. The primary focus must be on understanding the mechanisms linking central obesity to cardiac remodelling and dysfunction. The literature identifies several circulating factors and adipokines associated with visceral fat accumulation; however, the underlying pathways and molecular interactions remain unclear [145]. Longitudinal investigations must examine the temporal correlation between changes in central obesity measurements and cardiac remodelling progression, especially in individuals with normal BMI but high visceral fat deposits [80,146]. Moreover, researchers need to investigate the distinct effects of visceral and subcutaneous fat on cardiac function, considering the potential cardiovascular benefits of lower body fat distribution [147]. Further studies must analyse the synergistic effects between central obesity and other cardiovascular risk factors, including diabetes mellitus and hypertension, to assess their individual and combined influence on cardiac outcomes. The advancement of precise and economical methods for VAT measurement represents another essential research priority. Although MRI and CT scans provide detailed fat distribution analysis, their high costs and limited accessibility necessitate the development of alternative non-invasive techniques. Furthermore, there are significant variations in reference values for WC and WHR across different ethnic groups, highlighting the need for ethnicity-specific thresholds in diagnosing central obesity [148,149]. Although many developed countries have established cutoffs for WC and WHR, data remain insufficient for certain ethnic groups in developing countries. Addressing this gap requires further research to define appropriate cutoffs, accounting for diverse constitutional characteristics, such as body composition and fat distribution patterns [150,151]. Additionally, clinical trials must assess specific interventions targeting central obesity reduction, particularly, in individuals with normal BMI but increased central fat accumulation, to assess their effects on cardiac remodelling, function, and cardiovascular outcomes.

Conclusions

Central obesity, defined by excessive visceral fat accumulation, represents a major cardiovascular health risk, independently of general obesity indicators, such as BMI. Strong evidence demonstrates the direct link between central obesity and adverse cardiac remodelling, specifically, LV remodelling and dysfunction, leading to increased cardiovascular events and mortality (Figure). A complex network of metabolic, inflammatory, and hemodynamic mechanisms mediates the detrimental effects of central obesity on cardiac function, although these pathways need additional research. Moreover, these findings emphasise the clinical value of incorporating central obesity measurements, particularly, WC and WHR, into routine clinical assessments and research protocols to assess cardiovascular risk accurately. Additionally, implementing specific interventions targeting central obesity offers substantial potential to reduce cardiovascular disease burden and improve clinical outcomes in effected populations.

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The authors declare no conflicts of interest.

Author Contributions

K.S., A.M., A.S., and R.K. conceptualised and drafted the manuscript. K.S., A.M., A.P., M.S., Ch.A., A.S., and R.K. reviewed and edited the manuscript. A.S. and R.K. supervised. All authors approved the final version of the article.

References

[1] GBD 2019 Risk Factors Collaborators. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet. 2020;396:1223–49.

[2] Okunogbe A, Nugent R, Spencer G, Powis J, Ralston J, Wilding J. Economic impacts of overweight and obesity: current and future estimates for 161 countries. BMJ Glob Health. 2022;7:e009773.

[3] GBD 2021 Adult BMI Collaborators. Global, regional, and national prevalence of adult overweight and obesity, 1990–2021, with forecasts to 2050: a forecasting study for the Global Burden of Disease Study 2021. Lancet. 2025;405:813–38.

[4] Powell-Wiley TM, Poirier P, Burke LE, Després JP, Gordon-Larsen P, Lavie CJ, et al. Obesity and cardiovascular disease: a scientific statement from the American Heart Association. Circulation. 2021;143:e984–1010.

[5] Sohail MU, Aisha E, Waqas SA, Saad M, Arshad MS, Ahmed A, et al. Trends in obesity-related ischemic heart disease mortality among adults in the United States from 1999 to 2020. Future Cardiol. 2025.

[6] Van Gaal LF, Mertens IL, De Block CE. Mechanisms linking obesity with cardiovascular disease. Nature. 2006;444:875–80.

[7] Lopez-Jimenez F, Almahmeed W, Bays H, Cuevas A, Di Angelantonio E, le Roux CW, et al. Obesity and cardiovascular disease: mechanistic insights and management strategies. A joint position paper by the World Heart Federation and World Obesity Federation. Eur J Prev Cardiol. 2022;29:2218–37.

[8] Alpert MA, Omran J, Bostick BP. Effects of obesity on cardiovascular hemodynamics, cardiac morphology, and ventricular function. Curr Obes Rep. 2016;5:424–34.

[9] Alpert MA, Karthikeyan K, Abdullah O, Ghadban R. Obesity and cardiac remodeling in adults: mechanisms and clinical implications. Prog Cardiovasc Dis. 2018;61:114–23.

[10] Anjana M, Sandeep S, Deepa R, Vimaleswaran KS, Farooq S, Mohan V. Visceral and central abdominal fat and anthropometry in relation to diabetes in Asian Indians. Diabetes Care. 2004;27:2948–53.

[11] Mahabadi AA, Massaro JM, Rosito GA, Levy D, Murabito JM, Wolf PA, et al. Association of pericardial fat, intrathoracic fat, and visceral abdominal fat with cardiovascular disease burden: the Framingham Heart Study. Eur Heart J. 2009;30:850–6.

[12] Ren H, Guo Y, Wang D, Kang X, Yuan G. Association of normal-weight central obesity with hypertension: a cross-sectional study from the China health and nutrition survey. BMC Cardiovasc Disord. 2023;23:120.

[13] Smith JD, Borel AL, Nazare JA, Haffner SM, Balkau B, Ross R, et al. Visceral adipose tissue indicates the severity of cardiometabolic risk in patients with and without type 2 diabetes: results from the INSPIRE ME IAA study. J Clin Endocrinol Metab. 2012;97:1517–25.

[14] Carpentier AC. Hypertriglyceridemia associated with abdominal obesity: getting contributing factors into perspective. Arterioscler Thromb Vasc Biol. 2015;35:2076–8.

[15] Popiolek-Kalisz J, Szczygiel K. Bioelectrical impedance analysis and body composition in cardiovascular diseases. Curr Probl Cardiol. 2023;48:101911.

[16] Campa F, Coratella G, Cerullo G, Noriega Z, Francisco R, Charrier D, et al. High-standard predictive equations for estimating body composition using bioelectrical impedance analysis: a systematic review. J Transl Med. 2024;22:515.

[17] Catapano A, Trinchese G, Cimmino F, Petrella L, D'Angelo M, Di Maio G, et al. Impedance analysis to evaluate nutritional status in physiological and pathological conditions. Nutrients. 2023;15:2264.

[18] Wu Y, Li D, Vermund SH. Advantages and limitations of the body mass index (BMI) to assess adult obesity. Int J Environ Res Public Health. 2024;21:757.

[19] Bosomworth NJ. Normal-weight central obesity: unique hazard of the toxic waist. Can Fam Physician. 2019;65:399–408.

[20] Jin X, Liu J, Cao Q, Lin J, Wu G, Liu L, et al. Normal-weight central obesity: implications for diabetes mellitus. Front Nutr. 2023;10:1239493.

[21] Cornier MA, Després JP, Davis N, Grossniklaus DA, Klein S, Lamarche B, et al. Assessing adiposity: a scientific statement from the American Heart Association. Circulation. 2011;124:1996–2019.

[22] Deurenberg P, Yap M. The assessment of obesity: methods for measuring body fat and global prevalence of obesity. Baillieres Best Pract Res Clin Endocrinol Metab. 1999;13:1–11.

[23] Shuster A, Patlas M, Pinthus JH, Mourtzakis M. The clinical importance of visceral adiposity: a critical review of methods for visceral adipose tissue analysis. Br J Radiol. 2012;85:1–10.

[24] Mohammadi H, Ohm J, Discacciati A, Sundstrom J, Hambraeus K, Jernberg T, et al. Abdominal obesity and the risk of recurrent atherosclerotic cardiovascular disease after myocardial infarction. Eur J Prev Cardiol. 2020;27:1944–52.

[25] Ma WY, Yang CY, Shih SR, Hsieh HJ, Hung CS, Chiu FC, et al. Measurement of Waist Circumference: midabdominal or iliac crest? Diabetes Care. 2013;36:1660–6.

[26] Ostchega Y, Seu R, Sarafrazi N, Zhang G, Hughes JP, Miller I. Waist circumference measurement methodology study: national health and nutrition examination survey, 2016. Vital Health Stat. 2019;(182):1–20. 2.

[27] Khan I, Chong M, Le A, Mohammadi-Shemirani P, Morton R, Brinza C, et al. Surrogate adiposity markers and mortality. JAMA Netw Open. 2023;6:e2334836.

[28] Ashwell M. Obesity risk: importance of the waist-to-height ratio. Nurs Stand. 2009;23:49–55.

[29] Wang JW, Hu DY, Sun YH, Wang JH, Wang GL, Xie J, et al. Obesity criteria for identifying metabolic risks. Asia Pac J Clin Nutr. 2009;18:105–13.

[30] Nishida C, Ko GT, Kumanyika S. Body fat distribution and noncommunicable diseases in populations: overview of the 2008 WHO Expert Consultation on Waist Circumference and Waist-Hip Ratio. Eur J Clin Nutr. 2010;64:2–5.

[31] Chen Y, Zhang T, Qin B, Zhang R, Liu M, Guo R, et al. Comprehensive assessment of distinct abdominal fat compartments beyond liver content in overweight/obese patients using MRI and ultrasound imaging. Abdom Radiol (NY). 2025;50:1457–66.

[32] El-Koofy N, Soliman H, Elbarbary MA, Garhy ASE, Sheba M, Fouad H. Use of anthropometry versus ultrasound for the assessment of body fat and comorbidities in children with obesity. J Pediatr Gastroenterol Nutr. 2020;71:782–8.

[33] Liu KH, Chan YL, Chan WB, Kong WL, Kong MO, Chan JC. Sonographic measurement of mesenteric fat thickness is a good correlate with cardiovascular risk factors: comparison with subcutaneous and preperitoneal fat thickness, magnetic resonance imaging and anthropometric indexes. Int J Obes Relat Metab Disord. 2003;27:1267–73.

[34] Liu KH, Chan YL, Chan JC, Chan WB. Association of carotid intima-media thickness with mesenteric, preperitoneal and subcutaneous fat thickness. Atherosclerosis. 2005;179:299–304.

[35] Mizrahi I, Beglaibter N, Simanovsky N, Lioubashevsky N, Mazeh H, Ghanem M, et al. Ultrasound evaluation of visceral and subcutaneous fat reduction in morbidly obese subjects undergoing laparoscopic gastric banding, sleeve gastrectomy, and Roux-en-Y gastric bypass: a prospective comparison study. Obes Surg. 2015;25:959–66.

[36] Ponti F, De Cinque A, Fazio N, Napoli A, Guglielmi G, Bazzocchi A. Ultrasound imaging, a stethoscope for body composition assessment. Quant Imaging Med Surg. 2020;10:1699–722.

[37] Klopfenstein BJ, Kim MS, Krisky CM, Szumowski J, Rooney WD, Purnell JQ. Comparison of 3 T MRI and CT for the measurement of visceral and subcutaneous adipose tissue in humans. Br J Radiol. 2012;85:e826–30.

[38] Xu Z, Liu Y, Yan C, Yang R, Xu L, Guo Z, et al. Measurement of visceral fat and abdominal obesity by single-frequency bioelectrical impedance and CT: a cross-sectional study. BMJ Open. 2021;11:e048221.

[39] Hu HH, Nayak KS, Goran MI. Assessment of abdominal adipose tissue and organ fat content by magnetic resonance imaging. Obes Rev. 2011;12:e504–15.

[40] Dalah E, Hasan H, Madkour M, Obaideen A, Faris MAI. Assessing visceral and subcutaneous adiposity using segmented T2-MRI and multi-frequency segmental bioelectrical impedance: a sex-based comparative study. Acta Biomed. 2021;92:e2021078.

[41] Barnes S, Kinne E, Chowdhury S, Loong S, Moretz J, Sabate J. Comparison and precision of visceral adipose tissue measurement techniques in a multisite longitudinal study using MRI. Magn Reson Imaging. 2024;112:82–8.

[42] Murata H, Yagi T, Midorikawa T, Torii S, Takai E, Taguchi M. Comparison between DXA and MRI for the visceral fat assessment in athletes. Int J Sports Med. 2022;43:625–31.

[43] Lee MJ, Kim J. The pathophysiology of visceral adipose tissues in cardiometabolic diseases. Biochem Pharmacol. 2024;222:116116.

[44] Nicklas BJ, Penninx BWJH, Ryan AS, Berman DM, Lynch NA, Dennis KE. Visceral adipose tissue cutoffs associated with metabolic risk factors for coronary heart disease in women. Diabetes Care. 2003;26:1413–20.

[45] Lu X, Wang J, Sun H, Liu D, Yan X, Liu Z. Optimal cut-off values of visceral fat area for predicting metabolic syndrome among patients with ischemic stroke: a cross-sectional study. Front Neurol. 2024;15:1398907.

[46] Examination Committee of Criteria for 'Obesity Disease' in Japan, Japan Society for the Study of Obesity. New criteria for 'obesity disease' in Japan. Circ J. 2002;66:987–92.
[47] Morricone L, Malavazos AE, Coman C, Donati C, Hassan T, Caviezel F. Echocardiographic abnormalities in normotensive obese patients: relationship with visceral fat. Obes Res. 2002;10:489–98.
[48] Malavazos AE, Corsi MM, Ermetici F, Coman C, Sardanelli F, Rossi A, et al. Proinflammatory cytokines and cardiac abnormalities in uncomplicated obesity: relationship with abdominal fat deposition. Nutr Metab Cardiovasc Dis. 2007;17:294–302.
[49] Liu J, Li J, Pu H, He W, Zhou X, Tong N, et al. Cardiac remodeling and subclinical left ventricular dysfunction in adults with uncomplicated obesity: a cardiovascular magnetic resonance study. Quant Imaging Med Surg. 2022;12:2035–50.
[50] Nicklas BJ, Cesari M, Penninx BWJH, Kritchevsky SB, Ding J, Newman A, et al. Abdominal obesity is an independent risk factor for chronic heart failure in older people. J Am Geriatr Soc. 2006;54:413–20.
[51] Jayedi A, Soltani S, Zargar MS, Khan TA, Shab-Bidar S. Central fatness and risk of all cause mortality: systematic review and dose-response meta-analysis of 72 prospective cohort studies. BMJ. 2020;370:m3324.
[52] Wildman RP, McGinn AP, Lin J, Wang D, Muntner P, Cohen HW, et al. Cardiovascular disease risk of abdominal obesity vs. metabolic abnormalities. Obesity (Silver Spring). 2011;19:853–60.
[53] Sun Y, Liu B, Snetselaar LG, Wallace RB, Caan BJ, Rohan TE, et al. Association of normal-weight central obesity with all-cause and cause-specific mortality among postmenopausal women. JAMA Netw Open. 2019;2:e197337.
[54] Ueno K, Kaneko H, Kamiya K, Itoh H, Okada A, Suzuki Y, et al. Relationship of normal-weight central obesity with the risk for heart failure and atrial fibrillation: analysis of a nationwide health check-up and claims database. Eur Heart J Open. 2022;2:oeac026.
[55] Sahakyan KR, Somers VK, Rodriguez-Escudero JP, Hodge DO, Carter RE, Sochor O, et al. Normal-weight central obesity: implications for total and cardiovascular mortality. Ann Intern Med. 2015;163:827–35.
[56] German CA, Laughey B, Bertoni AG, Yeboah J. Associations between BMI, waist circumference, central obesity and outcomes in type II diabetes mellitus: the Accord Trial. J Diabetes Complications. 2020;34:107499.
[57] Li M, Zhu P, Wang SX. Risk for cardiovascular death associated with waist circumference and diabetes: a 9-year prospective study in the Wan Shou Lu cohort. Front Cardiovasc Med. 2022;9:856517.
[58] Fu L, Zhou Y, Sun J, Zhu Z, Tai S. Abdominal obesity is associated with an increased risk of all-cause mortality in males but not in females with HFpEF. Cardiovasc Ther. 2022;2022:2950055.
[59] Lakka HM, Lakka TA, Tuomilehto J, Salonen JT. Abdominal obesity is associated with increased risk of acute coronary events in men. Eur Heart J. 2002;23:706–13.
[60] Dagenais GR, Yi Q, Mann JFE, Bosch J, Pogue J, Yusuf S. Prognostic impact of body weight and abdominal obesity in women and men with cardiovascular disease. Am Heart J. 2005;149:54–60.
[61] Djoussé L, Bartz TM, Ix JH, Zieman SJ, Delaney JA, Mukamal KJ, et al. Adiposity and incident heart failure in older adults: the cardiovascular health study. Obesity (Silver Spring). 2012;20:1936–41.
[62] Ramezankhani A, Azizi F, Hasheminia M, Hadaegh F. The impact of general and central obesity for all-cause hospitalization among Iranian adults: a 20 year follow-up-results from the TLGS cohort. BMC Public Health. 2023;23:903.
[63] Liu J, Jin X, Feng Z, Huang J. The association of central and extremity circumference with all-cause mortality and cardiovascular mortality: a cohort study. Front Cardiovasc Med. 2023;10:1251619.
[64] Cabrera MAS, Gebara OCE, Diament J, Nussbacher A, Rosano G, Wajngarten M. Metabolic syndrome, abdominal obesity, and cardiovascular risk in elderly women. Int J Cardiol. 2007;114:224–9.
[65] Ammar KA, Redfield MM, Mahoney DW, Johnson M, Jacobsen SJ, Rodeheffer RJ. Central obesity: association with left ventricular dysfunction and mortality in the community. Am Heart J. 2008;156:975–81.
[66] Alpert MA, Chan EJ. Left ventricular morphology and diastolic function in severe obesity: current views. Rev Esp Cardiol (Engl Ed). 2012;65:1–3.
[67] Gade S, Sahasrabuddhe AV, Mohite KA, Bankar NJ, Chaudhary SS, Muley PA, et al. Effect of obesity on left ventricular systolic and diastolic functions based on echocardiographic indices. Cureus. 2023;15:e37232.
[68] Abel ED, Litwin SE, Sweeney G. Cardiac remodeling in obesity. Physiol Rev. 2008;88:389–419.
[69] Woodiwiss AJ, Libhaber CD, Majane OHI, Libhaber E, Maseko M, Norton GR. Obesity promotes left ventricular concentric rather than eccentric geometric remodeling and hypertrophy independent of blood pressure. Am J Hypertens. 2008;21:1144–51.
[70] Turkbey EB, McClelland RL, Kronmal RA, Burke GL, Bild DE, Tracy RP, et al. The impact of obesity on the left ventricle: the Multi-Ethnic Study of Atherosclerosis (MESA). JACC Cardiovasc Imaging. 2010;3:266–74.
[71] Woodiwiss AJ, Norton GR. Obesity and left ventricular hypertrophy: the hypertension connection. Curr Hypertens Rep. 2015;17:539.
[72] Cuspidi C, Rescaldani M, Sala C, Grassi G. Left-ventricular hypertrophy and obesity: a systematic review and meta-analysis of echocardiographic studies. J Hypertens. 2014;32:16–25.
[73] Tsioufis CP, Tsiachris DL, Selima MN, Dimitriadis KS, Thomopoulos CG, Tsiliggiris DC, et al. Impact of waist circumference on cardiac phenotype in hypertensives according to gender. Obesity (Silver Spring). 2009;17:177–82.
[74] Eschalier R, Rossignol P, Kearney-Schwartz A, Adamopoulos C, Karatzidou K, Fay R, et al. Features of cardiac remodeling, associated with blood pressure and fibrosis biomarkers, are frequent in subjects with abdominal obesity. Hypertension. 2014;63:740–6.
[75] Son JW, Sung JK, Lee JW, Youn YJ, Ahn MS, Ahn SG, et al. Abdominal obesity and structure and function of the heart in healthy male Koreans: the ARIRANG study. Medicine (Baltimore). 2016;95:e4930.
[76] Tadic M, Ivanovic B, Celic V, Neskovic A. Do nondipping pattern and metabolic syndrome impact left ventricular geometry and global function in hypertensive patients? Clin Exp Hypertens. 2013;35:637–44.
[77] Russo C, Sera F, Jin Z, Palmieri V, Homma S, Rundek T, et al. Abdominal adiposity, general obesity, and subclinical systolic dysfunction in the elderly: a population-based cohort study. Eur J Heart Fail. 2016;18:537–44.
[78] Marttila J, Sipola P, Juutilainen A, Sillanmäki S, Hedman M, Kuusisto J. Central obesity is associated with increased left ventricular maximal wall thickness and intrathoracic adipose tissue measured with cardiac magnetic resonance. High Blood Press Cardiovasc Prev. 2024;31:389–99.
[79] Cho DH, Kim MN, Joo HJ, Shim WJ, Lim DS, Park SM. Visceral obesity, but not central obesity, is associated with cardiac remodeling in subjects with suspected metabolic syndrome. Nutr Metab Cardiovasc Dis. 2019;29:360–6.
[80] Mandry D, Girerd N, Lamiral Z, Huttin O, Filippetti L, Micard E, et al. Arterial and cardiac remodeling associated with extra weight gain in an isolated abdominal obesity cohort. Front Cardiovasc Med. 2021;8:771022.
[81] Gao Y, Zeng J, Zou F, Zhang X, Qian Z, Wang Y, et al. Causal effect of central obesity on left ventricular structure and function in preserved EF population: a Mendelian randomization study. Front Cardiovasc Med. 2022;9:1103011.
[82] Share BL, La Gerche A, Naughton GA, Obert P, Kemp JG. Young women with abdominal obesity have subclinical myocardial dysfunction. Can J Cardiol. 2015;31:1195–201.
[83] Selvaraj S, Martinez EE, Aguilar FG, Kim KYA, Peng J, Sha J, et al. Association of central adiposity with adverse cardiac mechanics: findings from the hypertension genetic epidemiology network study. Circ Cardiovasc Imaging. 2016;9:e004396. https://doi.org/10.1161/CIRCIMAGING.115.004396.
[84] Chirinos JA, Sardana M, Satija V, Gillebert TC, De Buyzere ML, Chahwala J, et al. Effect of obesity on left atrial strain in persons aged 35–55 years (the Asklepios Study). Am J Cardiol. 2019;123:854–61.
[85] Sezenöz B, Ünlü S, Yalçın Y, Yamak BA, Yazgan E, Türkoğlu S, et al. The effect of body weight on left atrial function determined by longitudinal strain analysis in young adults. Int J Cardiovasc Imaging. 2024;40:407–14.
[86] Deal O, Rayner J, Stracquadanio A, Wijesurendra RS, Neubauer S, Rider O, et al. Effect of weight loss on early left atrial myopathy in people with obesity but no established cardiovascular disease. J Am Heart Assoc. 2022;11:e026023.
[87] Reddy YNV, Anantha-Narayanan M, Obokata M, Koepp KE, Erwin P, Carter RE, et al. Hemodynamic effects of weight loss in obesity: a systematic review and meta-analysis. JACC Heart Fail. 2019;7:678–87.
[88] Cavalera M, Wang J, Frangogiannis NG. Obesity, metabolic dysfunction, and cardiac fibrosis: pathophysiological pathways, molecular mechanisms, and therapeutic opportunities. Transl Res. 2014;164:323–35.
[89] Pou KM, Massaro JM, Hoffmann U, Vasan RS, Maurovich-Horvat P, Larson MG, et al. Visceral and subcutaneous adipose tissue volumes are cross-sectionally related to markers of inflammation and oxidative stress: the Framingham Heart Study. Circulation. 2007;116:1234–41.

[90] Neeland IJ, Ayers CR, Rohatgi AK, Turer AT, Berry JD, Das SR, et al. Associations of visceral and abdominal subcutaneous adipose tissue with markers of cardiac and metabolic risk in obese adults. Obesity (Silver Spring). 2013;21:E439–47.
[91] Lampe L, Zhang R, Beyer F, Huhn S, Kharabian Masouleh S, Preusser S, et al. Visceral obesity relates to deep white matter hyperintensities via inflammation. Ann Neurol. 2019;85:194–203.
[92] Sawaki D, Czibik G, Pini M, Ternacle J, Suffee N, Mercedes R, et al. Visceral adipose tissue drives cardiac aging through modulation of fibroblast senescence by osteopontin production. Circulation. 2018;138:809–22.
[93] Alvehus M, Burén J, Sjöström M, Goedecke J, Olsson T. The human visceral fat depot has a unique inflammatory profile. Obesity (Silver Spring). 2010;18:879–83.
[94] Kranendonk MEG, van Herwaarden JA, Stupkova T, de Jager W, Vink A, Moll FL, et al. Inflammatory characteristics of distinct abdominal adipose tissue depots relate differently to metabolic risk factors for cardiovascular disease: distinct fat depots and vascular risk factors. Atherosclerosis. 2015;239:419–27.
[95] Mamazhakypov A, Sartmyrzaeva M, Sarybaev AS, Schermuly R, Sydykov A. Clinical and molecular implications of osteopontin in heart failure. Curr Issues Mol Biol. 2022;44:3573–97.
[96] Kojta I, Chacińska M, Błachnio-Zabielska A. Obesity, bioactive lipids, and adipose tissue inflammation in insulin resistance. Nutrients. 2020;12:1305.
[97] Ghosh A, Bose K, Das Chaudhuri AB. Association of food patterns, central obesity measures and metabolic risk factors for coronary heart disease (CHD) in middle aged Bengalee Hindu men, Calcutta, India. Asia Pac J Clin Nutr. 2003;12:166–71.
[98] Alser M, Naja K, Elrayess MA. Mechanisms of body fat distribution and gluteal-femoral fat protection against metabolic disorders. Front Nutr. 2024;11:1368966.
[99] Muniyappa R, Noureldin R, Ouwerkerk R, Liu EY, Madan R, Abel BS, et al. Myocardial fat accumulation is independent of measures of insulin sensitivity. J Clin Endocrinol Metab. 2015;100:3060–8.
[100] Egom EE. BNP and heart failure: preclinical and clinical trial data. J Cardiovasc Transl Res. 2015;8:149–57.
[101] Egom EEA. Natriuretic peptide clearance receptor (NPR-C) pathway as a novel therapeutic target in obesity-related heart failure with preserved ejection fraction (HFpEF). Front Physiol. 2021;12:674254.
[102] Sangaralingham SJ, Kuhn M, Cannone V, Chen HH, Burnett JC. Natriuretic peptide pathways in heart failure: further therapeutic possibilities. Cardiovasc Res. 2023;118:3416–33.
[103] Roxana ME, Georgică T, Ionuț D, Gianina M, Cristina F. Atrial and brain natriuretic peptides- benefits and limits of their use in cardiovascular diseases. Curr Cardiol Rev. 2019;15:283–90.
[104] Cheng S, Fox CS, Larson MG, Massaro JM, McCabe EL, Khan AM, et al. Relation of visceral adiposity to circulating natriuretic peptides in ambulatory individuals. Am J Cardiol. 2011;108:979–84.
[105] Park SJ, Cho KI, Jung SJ, Choi SW, Choi JW, Lee DW, et al. N-terminal pro-B-type natriuretic Peptide in overweight and obese patients with and without diabetes: an analysis based on body mass index and left ventricular geometry. Korean Circ J. 2009;39:538–44.
[106] Wang TJ, Larson MG, Levy D, Benjamin EJ, Leip EP, Wilson PWF, et al. Impact of obesity on plasma natriuretic peptide levels. Circulation. 2004;109:594–600.
[107] Fox ER, Musani SK, Bidulescu A, Nagarajarao HS, Samdarshi TE, Gebreab SY, et al. Relation of obesity to circulating B-type natriuretic peptide concentrations in blacks: the Jackson Heart Study. Circulation. 2011;124:1021–7.
[108] Wester M, Hegner P, Tafelmeier M, Rupprecht L, Schmid C, Maier LS, et al. Body mass index and NT-pro-BNP in high-risk cardiac patients. Dtsch Arztebl Int. 2025;122:57–8.
[109] de Andrade EN, Gonçalves GKN, de Oliveira THC, Santos CSD, Souza CLSE, Firmes LB, et al. Natriuretic peptide system: a link between fat mass and cardiac hypertrophy and hypertension in fat-fed female rats. Regul Pept. 2011;167:149–55.
[110] Sarzani R, Spannella F, Giulietti F, Balietti P, Cocci G, Bordicchia M. Cardiac natriuretic peptides, hypertension and cardiovascular risk. High Blood Press Cardiovasc Prev. 2017;24:115–26.
[111] Clerico A, Giannoni A, Vittorini S, Emdin M. The paradox of low BNP levels in obesity. Heart Fail Rev. 2012;17:81–96.
[112] Datta T, Lee AJ, Cain R, McCarey M, Whellan DJ. Weighing in on heart failure: the potential impact of bariatric surgery. Heart Fail Rev. 2022;27:755–66.
[113] Sargsyan N, Chen JY, Aggarwal R, Fadel MG, Fehervari M, Ashrafian H. The effects of bariatric surgery on cardiac function: a systematic review and meta-analysis. Int J Obes (Lond). 2024;48:166–76.
[114] Esparham A, Shoar S, Kheradmand HR, Ahmadyar S, Dalili A, Rezapanah A, et al. The impact of bariatric surgery on cardiac structure, and systolic and diastolic function in patients with obesity: a systematic review and meta-analysis. Obes Surg. 2023;33:345–61.
[115] Huang S, Lan Y, Zhang C, Zhang J, Zhou Z. The early effects of bariatric surgery on cardiac structure and function: a systematic review and meta-analysis. Obes Surg. 2023;33:453–68.
[116] Ashrafian H, Athanasiou T, le Roux CW. Heart remodelling and obesity: the complexities and variation of cardiac geometry. Heart. 2011;97:171–2.
[117] Rozandal V, Mishima R, Garcia M, Berdeja N, Vambakianos PNM, Valdez M, et al. Cardiac remodeling after bariatric surgery beyond weight loss: a dose-response analysis. Obes Surg. 2025;35:1638–48.
[118] Zheng Z, Zong Y, Ma Y, Tian Y, Pang Y, Zhang C, et al. Glucagon-like peptide-1 receptor: mechanisms and advances in therapy. Signal Transduct Target Ther. 2024;9:234.
[119] Shchendrygina A, Rakisheva A, Giverts I, Rustamova Y, Soloveva A. Effects of glucagon-like peptide-1 receptor agonists on cardiac function, exercise capacity and quality of life. Card Fail Rev. 2024;10:e10.
[120] Arrowaili A. Efficacy and safety of GLP- 1 receptor agonists in the management of weight recurrence or suboptimal clinical response after undergoing metabolic bariatric surgeries: a meta-analysis. Obes Surg. 2025;35:1947–60.
[121] Huixing L, Di F, Daoquan P. Effect of glucagon-like Peptide-1 receptor agonists on prognosis of heart failure and cardiac function: a systematic review and meta-analysis of randomized controlled trials. Clin Ther. 2023;45:17–30.
[122] Ussher JR, Drucker DJ. Glucagon-like peptide 1 receptor agonists: cardiovascular benefits and mechanisms of action. Nat Rev Cardiol. 2023;20:463–74.
[123] Liao C, Liang X, Zhang X, Li Y. The effects of GLP-1 receptor agonists on visceral fat and liver ectopic fat in an adult population with or without diabetes and nonalcoholic fatty liver disease: a systematic review and meta-analysis. PLoS One. 2023;18:e0289616.
[124] Henry JA, Abdesselam I, Deal O, Lewis AJ, Rayner J, Bernard M, et al. The effect of bariatric surgery type on cardiac reverse remodelling. Int J Obes (Lond). 2024;48:808–14.
[125] Sorimachi H, Obokata M, Omote K, Reddy YNV, Takahashi N, Koepp KE, et al. Long-term changes in cardiac structure and function following bariatric surgery. J Am Coll Cardiol. 2022;80:1501–12.
[126] Olson KL, Neiberg RH, Espeland MA, Johnson KC, Knowler WC, Pi-Sunyer X, et al. Waist circumference change during intensive lifestyle intervention and cardiovascular morbidity and mortality in the look AHEAD Trial. Obesity (Silver Spring). 2020;28:1902–11.
[127] Smith SC Jr, Haslam D. Abdominal obesity, waist circumference and cardio-metabolic risk: awareness among primary care physicians, the general population and patients at risk–the Shape of the Nations survey. Curr Med Res Opin. 2007;23:29–47.
[128] Szabo L, McCracken C, Cooper J, Rider OJ, Vago H, Merkely B, et al. The role of obesity-related cardiovascular remodelling in mediating incident cardiovascular outcomes: a population-based observational study. Eur Heart J Cardiovasc Imaging. 2023;24:921–9.
[129] Rexrode KM, Carey VJ, Hennekens CH, Walters EE, Colditz GA, Stampfer MJ, et al. Abdominal adiposity and coronary heart disease in women. JAMA. 1998;280:1843–8.
[130] Suk SH, Sacco RL, Boden-Albala B, Cheun JF, Pittman JG, Elkind MS, et al. Abdominal obesity and risk of ischemic stroke: the Northern Manhattan Stroke Study. Stroke. 2003;34:1586–92.
[131] Sorimachi H, Omote K, Omar M, Popovic D, Verbrugge FH, Reddy YNV, et al. Sex and central obesity in heart failure with preserved ejection fraction. Eur J Heart Fail. 2022;24:1359–70.
[132] Lee CMY, Huxley RR, Wildman RP, Woodward M. Indices of abdominal obesity are better discriminators of cardiovascular risk factors than BMI: a meta-analysis. J Clin Epidemiol. 2008;61:646–53.
[133] Czernichow S, Kengne AP, Stamatakis E, Hamer M, Batty GD. Body mass index, waist circumference and waist-hip ratio: which is the better discriminator of cardiovascular disease mortality risk?: evidence from an individual-participant meta-analysis of 82 864 participants from nine cohort studies. Obes Rev. 2011;12:680–7.
[134] Dybala MP, Brady MJ, Hara M. Disparity in adiposity among adults with normal body mass index and waist-to-height ratio. iScience. 2019;21:612–23.

[135] Jensen MD. Role of body fat distribution and the metabolic complications of obesity. J Clin Endocrinol Metab. 2008;93(Suppl 1):S57–63.
[136] Manolopoulos KN, Karpe F, Frayn KN. Gluteofemoral body fat as a determinant of metabolic health. Int J Obes (Lond). 2010;34:949–59.
[137] Snijder MB, Dekker JM, Visser M, Bouter LM, Stehouwer CDA, Yudkin JS, et al. Trunk fat and leg fat have independent and opposite associations with fasting and postload glucose levels: the Hoorn study. Diabetes Care. 2004;27:372–7.
[138] Raheem J, Sliz E, Shin J, Holmes MV, Pike GB, Richer L, et al. Visceral adiposity is associated with metabolic profiles predictive of type 2 diabetes and myocardial infarction. Commun Med (Lond). 2022;2:81.
[139] Xia MF, Chen Y, Lin HD, Ma H, Li XM, Aleteng Q, et al. A indicator of visceral adipose dysfunction to evaluate metabolic health in adult Chinese. Sci Rep. 2016;6:38214.
[140] Cole TJ, Lobstein T. Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. Pediatr Obes. 2012;7:284–94.
[141] Tsigos C, Hainer V, Basdevant A, Finer N, Fried M, Mathus-Vliegen E, et al. Management of obesity in adults: European clinical practice guidelines. Obes Facts. 2008;1:106–16.
[142] Alberti KGMM, Zimmet P, Shaw J. IDF Epidemiology Task Force Consensus Group. The metabolic syndrome–a new worldwide definition. Lancet. 2005;366:1059–62.
[143] Ntuk UE, Gill JMR, Mackay DF, Sattar N, Pell JP. Ethnic-specific obesity cutoffs for diabetes risk: cross-sectional study of 490,288 UK Biobank participants. Diabetes Care. 2014;37:2500–7.
[144] Katzmarzyk PT, Bray GA, Greenway FL, Johnson WD, Newton RL Jr, Ravussin E, et al. Ethnic-specific BMI and waist circumference thresholds. Obesity (Silver Spring). 2011;19:1272–8.
[145] Deng Y, Scherer PE. Adipokines as novel biomarkers and regulators of the metabolic syndrome. Ann N Y Acad Sci. 2010;1212:E1–19.
[146] Antonini-Canterin F, Di Nora C, Poli S, Sparacino L, Cosei I, Ravasel A, et al. Obesity, cardiac remodeling, and metabolic profile: validation of a new simple index beyond body mass index. J Cardiovasc Echogr. 2018;28:18–25.
[147] Neeland IJ, Turer AT, Ayers CR, Berry JD, Rohatgi A, Das SR, et al. Body fat distribution and incident cardiovascular disease in obese adults. J Am Coll Cardiol. 2015;65:2150–1.
[148] Lear SA, James PT, Ko GT, Kumanyika S. Appropriateness of waist circumference and waist-to-hip ratio cutoffs for different ethnic groups. Eur J Clin Nutr. 2010;64:42–61.
[149] Stults-Kolehmainen MA, Stanforth PR, Bartholomew JB, Lu T, Abolt CJ, Sinha R. DXA estimates of fat in abdominal, trunk and hip regions varies by ethnicity in men. Nutr Diabetes. 2013;3:e64.
[150] Sakibaev KS, Nikityuk DB, Alimbekova AA, Mamashov NM, Dzhumaev RM, Dzholdosheva GT. Constitutional characteristics of physical development in the Kyrgyz population. BIO Web Conf. 2021;29:01011.
[151] Nuruev M, Sakibaev K, Dzholdosheva G, Maksimova K, Kanymgul AK. Features of circumference sizes in women of different constitutional groups. Clin Physiol Funct Imaging. 2023;43:40–6.