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Original article

Predictive values of relative fat mass and body mass index on cardiovascular health in community-dwelling older adults: Results from the Longevity Check-up (Lookup) 7+

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ABSTRACT

Objectives: To assess the predictive value of relative fat mass compared to body mass index for hypertension, diabetes, hyperlipidemia, and heightened cardiovascular risk in a cohort of community-dwelling older adults from the Longevity Check-up 7+ cohort.

Study design: Retrospective cross-sectional study.

Main outcome measures: Hyperlipidemia was defined as total cholesterol ≥200 mg/dL or ongoing lipid-lowering treatment. Diabetes was defined either as self-reported diagnosis or fasting blood glucose >126 mg/dL or a random blood glucose >200 mg/dL. Hypertension was defined as blood pressure ≥ 140/90 mmHg or requiring daily antihypertensive medications. Heightened cardiovascular risk was operationalized as having at least two of these conditions.

Results: Analyses were conducted in 1990 participants (mean age 73.2 ± 6.0 years; 54.1 % women). Higher proportions of men than women had hypertension and diabetes, while hyperlipidemia was more prevalent in women. Receiver operating curve analysis indicated relative fat mass was a better predictor of hypertension in women and diabetes in both sexes. Body mass index performed better in predicting hyperlipidemia in women. Relative fat mass thresholds of ≥27 % for men and ≥40 % for women were identified as optimal indicators of heightened cardiovascular risk and so were used to defined high adiposity. Moderate correlations were found between high adiposity or body mass index ≥25 kg/m^2 and the presence of hypertension, hyperlipidemia and heightened cardiovascular risk, while a strong correlation was found with diabetes. Logistic regression analysis highlighted significant associations between high adiposity and increased odds of hypertension, diabetes, and heightened cardiovascular risk.

Conclusions: Proposed cut-offs for relative fat mass were more reliable indices than the usual cut-offs for body mass index for identifying individuals at heightened cardiovascular risk. Our findings support the role of anthropometric measures in evaluating body composition and the associated metabolic and cardiovascular conditions in older adults.

Abbreviations: AUC, area under the curve; BIA, bioelectrical impedance analysis; BMI, body mass index; BP, blood pressure; CI, confidence intervals; CRFs, cardiovascular risk factors; CVD, cardiovascular disease; DXA, dual energy X-ray absorptiometry; H-CVR, heightened cardiovascular risk; MS, metabolic syndrome; OR, odds ratio; ROC, receiver operating characteristic; RFM, relative fat mass; WC, waist circumference.

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1. Introduction

Cardiovascular disease (CVD) is the leading cause of death and non-communicable diseases worldwide [1,2]. Cardiovascular risk factors (CRFs) such as excess body weight, high blood pressure (BP), diabetes, high low-density lipoprotein cholesterol, and active smoking are responsible for more than half of new CVD diagnoses and one fifth of 10-year mortality [3]. Assessing and managing cardiovascular risk are particularly relevant in older adults, as advancing age itself is a predisposing factor for CVD [4]. Moreover, aging is often accompanied by fat accumulation at the expenses of lean body mass, with significant metabolic and cardiovascular consequences [5]. Therefore, being able to quantify fat mass using simple indirect measures is critical for its assessment and monitoring. The most used tool to estimate body adiposity in the general population is body mass index (BMI). BMI values ≥ 25 kg/m^2 and ≥ 30 kg/m^2 identify the presence of overweight and obesity, respectively, and have been linked to an increased risk of multimorbidity and death [6,7]. Recent literature has questioned the validity of BMI in identifying excessive adiposity and its associated outcomes, since there is evidence suggesting that BMI may wrongly classify a considerable number of individuals with high amounts of body fat as non-obese or metabolically healthy [8,9]. Several novel methods for estimating whole-body fat based on anthropometric parameters have been proposed and validated [10–12]. Among them, relative fat mass (RFM) showed to be particularly promising in assessing whole-body adiposity especially in older adults [12–14].

In the general population, a higher RFM has been associated with increased incidence and severity of diabetes and CVD [15–20]. In older adults, RFM was found to be sensitive to the modifications of body composition following an exercise- and caloric restriction-based 12-month weight loss intervention [21], as well as cross-sectionally associated with adherence to a Mediterranean-style dietary pattern [22]. There is significant agreement between RFM and direct measures of adiposity, including those obtained by dual energy X-ray absorptiometry (DXA) and magnetic resonance imaging, especially among old women [21,23]. However, further evidence is needed to assess the accuracy of RFM for predicting cardiovascular risk in older populations. To this aim, the present study was conducted to compare the predictive value of RFM and BMI at identifying poor control of modifiable cardiovascular health metrics such as blood lipids, blood glucose, and BP in a cohort of community-dwelling older adults. We also calculated RFM cut-offs to identify individuals with heightened cardiovascular risk (H-CVR), defined as having at least two among the abovementioned CRFs.

2. Materials and methods

This was retrospective cross-sectional study conducted using data from the Longevity Check-up 7+ (Lookup7+) project. Lookup 7+ is an ongoing initiative sponsored by the Department of Geriatrics of the Università Cattolica del Sacro Cuore and the Fondazione Policlinico Universitario “Agostino Gemelli” IRCCS (Rome, Italy). Prior to enrollment, all individuals provided written informed consent. The Ethics Committee of the Università Cattolica del Sacro Cuore approved the protocol of the study (protocol #A.1220/CE/2011). The study protocol is extensively described elsewhere [24].

2.1. Study sample

Analyses for the current research were performed in individuals aged 65 years or more. Exclusion criteria were refusal to undergo capillary blood testing to measure total cholesterol and glycemia and unwillingness or incapacity to provide a written informed consent. Participants were recruited in public places and events. Cities of different sizes were chosen to ensure a comprehensive geographic representation of mainland Italy and its major islands. In major cities such as Rome, Milan, Naples, Genoa, Bologna, and Catania, several initiatives were implemented across diverse locations to provide a thorough representation of the sociodemographic characteristics of residents across different places.

2.2. Cardiovascular health metrics

Cardiovascular health metrics were evaluated using a lifestyle habits questionnaire and a brief check-up that included blood pressure measurements and point-of-care tests for total cholesterol and blood glucose. Smoking status was classified as current smoker (has smoked ≥ 100 cigarettes in lifetime and currently smokes cigarettes), never smoked (never smoked or smoked <100 cigarettes in lifetime), or former smoker (smoked at least 100 cigarettes in lifetime but quit within 28 days of interview). For the analyses, smoking status was categorized as current or never/former smoker. Healthy diet was operationalized as a daily consumption of at least three portions (~ 400 g) of fruit and/or vegetables per day [25]. The daily intake of fruit and vegetables was calculated based on reference tables for the Italian population released by the Italian Society of Nutrition (SINU) [26]. Regular participation in physical activity or exercise was defined as engaging in activities for at least 30 min at least two times a week over the previous year. Participants were asked, “In the last 12 months, have you engaged in physical activity or exercise for at least 30 minutes, twice a week or more? If yes, please specify the activity”. The activities evaluated included: (a) light walking for physical activity, (b) running, cycling, or swimming, and (c) strength training with or without stretching exercises. Based on their responses, participants were classified as (a) inactive (not engaging in at least 30 min of physical activity or physical exercise twice weekly), (b) light walkers, (c) engaged in running, cycling, or swimming, (d) engaged in strength training with or without stretching, and (e) engaged in light walking in addition to any other physical exercise. This classification was chosen to acknowledge that physical activity, such as walking, and physical exercise are different in terms of their structure and intensity [27,28]. For the analyses, participants were categorized as physically active and inactive. Total cholesterol was measured from capillary blood samples using disposable strips based on a reflectometric system with a portable device (MultiCare-In, Biomedical Systems International srl, Florence Italy) [29]. Total cholesterol was categorized as <200 mg/dL (if untreated), 200–239 mg/dL (or treated to goal), and ≥ 240 mg/dL. Hyperlipidemia was defined as having total cholesterol ≥ 200 mg/dL or ongoing lipid-lowering treatment. Blood glucose was measured from capillary blood samples using disposable strips based on an amperometric system with a MultiCare-In portable device [29]. Diabetes was defined either as self-reported diagnosis or fasting blood glucose >126 mg/dL or a random blood glucose >200 mg/dL. BP was measured with an electronic sphygmomanometer according to recommendations from European guidelines [30]. BP values were categorized as $<120/80$ mmHg (if untreated), 120/80–139/89 mmHg (or treated to goal) and $\geq 140/90$ mmHg. Hypertension was defined as untreated BP $\geq 140/90$ mmHg or requiring daily antihypertensive medications.

Hyperlipidemia, diabetes, and hypertension were considered CRFs of interest. Participants were considered as having an H-CVR if they had at least two among the aforementioned conditions.

2.3. Obesity assessment and relative fat mass estimation

Body weight and height were measured using an analog scale with a built-in stadiometer. The BMI was calculated as the ratio between body weight (in kg) and the square of height (in m^2). An anthropometric tape was used to measure the participant’s waist circumference (WC) as they stood with their feet together, head straight, eyes forward, and their arms at their sides. The measurement was taken at the midpoint between the last floating rib and the highest point of the iliac crest. RFM was calculated using the following equation [12]:

$$\mathrm{RFM} = 64 - \left(20 \times \frac{\text{height (cm)}}{\text{waist circumference (cm)}}\right) + (12 \times \text{sex})$$

where sex = 0 for men and 1 for women.

Woolcott and Bergman identified RFM values ≥30 % or ≥40 % in males and females, respectively, as rounded cutoffs to identify individuals at higher risk of death [31]. As detailed later, in our study optimal cutoffs for RFM for predicting CRFs were determined using the Youden index. Therefore, high adiposity was operationalized as having RFM equal to or higher than the optimal threshold for identifying H-CVR individuals.

2.4. *Statistical analysis*

Descriptive statistics were used to summarize the main personal and anthropometric characteristics of study participants according to sex. Continuous variables were provided as mean ± standard deviation, and categorical variables were presented as absolute frequencies and percentages. Differences in means and proportions were assessed using *t*-test and chi-squared test, respectively. Receiver operating characteristic (ROC) curves were used to assess the ability of RFM and BMI to predict hypertension, diabetes, hyperlipidemia and H-CVR, and to identify the optimal cutoff value in males and females using the Youden index [32]. The DeLong method was used to compare the differences between the areas under the curve (AUC) for RFM, BMI, and each of the three CRFs, as well as H-CVR. Prevalence of hypertension, diabetes, hyperlipidemia, and H-CVR across participants with high RFM and BMI-defined overweight and obesity were compared using chi-squared statistics. Cohen's kappa was used to appraise inter-rater reliability between individuals having both high adiposity and BMI ≥25 kg/m^2 and between a combination of high adiposity or BMI ≥25 kg/m^2 and each of the CRFs or H-CVR. Youden index (J-index) was calculated to compare sensitivity and specificity of RFM and BMI cutoff values for predicting hypertension, diabetes, hyperlipidemia, and H-CVR. The relationship between high adiposity and CRFs was examined using logistic regression. First, unadjusted odds ratios (ORs) and their corresponding 95 % confidence intervals (CIs) were calculated. Subsequently, logistic regression models were constructed, incorporating adjustments for age, sex, and other variables found to be linked to increased adiposity at the univariate analysis. All analyses were performed using R version 4.2.3 (R Core Team, Vienna, Austria).

3. Results

Between 1 June 2015 and 30 January 2023, a total of 4720 participants aged 65 years or more were enrolled across Italy. Among them, 2730 were excluded due to missing values in the variables of interest (Fig. 1). Therefore, 1990 individuals were considered for the present study. Personal and anthropometric characteristics of excluded participants did not significantly differ from those included in the analyses.

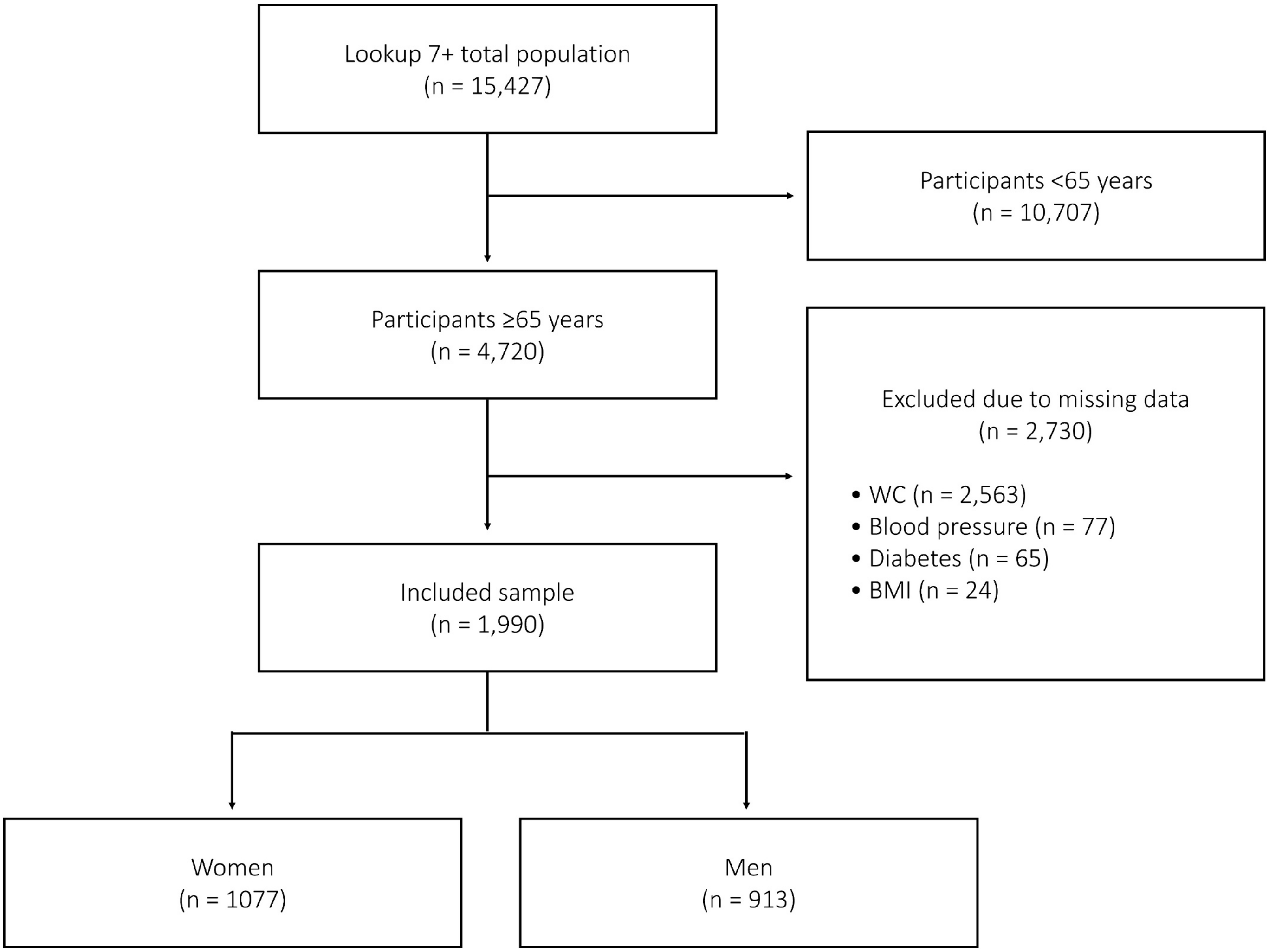

Fig. 1. Flowchart on the sample selection.
Abbreviations: BMI: body mass index; WC: waist circumference.

The main characteristics of study participants according to sex are showed in Table 1. The mean age of the participants was 73.2 ± 6.0 years and 1077 (54.1 %) were women. Male participants were approximately one year older than women. The two groups did not significantly differ for active smoking and physical inactivity, but a higher proportion of females followed a healthy diet. Men showed higher prevalence of hypertension and diabetes, while a higher proportion of females had hyperlipidemia. BMI was one-point higher in males, but no differences were found in the prevalence of overweight or obesity between sexes. RFM was higher in females.

Fig. 2 shows ROC curves evaluating RFM and BMI for predicting hypertension, diabetes, hyperlipidemia and H-CVR in both males and females. By comparing AUCs, ROC analysis indicated RFM was a better predictor of hypertension in females ($p = 0.049$) and diabetes in both males ($p = 0.004$) and females ($p = 0.010$). BMI performed better in predicting hyperlipidemia in females ($p = 0.041$). No significant differences in AUCs were observed for hypertension or hyperlipidemia in males and for H-CVR in both males and females (Table 2 and Table 3). Based on ROC analysis, rounded optimal RFM cutoffs for predicting the presence of H-CVR were 27 % for males and 40 % for females.

Table 2 shows comparisons in the prevalence of CRFs in participants with optimal and pre-defined cutoffs for RFM and BMI in male participants. The lowest prevalence of hypertension was found for BMI ≥30 kg/m^2 (11.0 %), while the highest prevalence was observed for RFM ≥27 % (57.9 %), with statistically significant differences among all four groups ($p < 0.001$). For diabetes, the highest prevalence was found for RFM ≥27 % (15.0 %) and BMI ≥25 kg/m^2 (12.8 %), without statistically significant differences between the two groups ($p = 0.199$), while the lowest prevalence was reported for BMI ≥30 kg/m^2 (3.8 %, p < 0.001). No differences were found between RFM ≥30 % and BMI ≥25 kg/m^2 ($p = 0.055$). All remaining differences between groups were statistically significant (p < 0.001). For hyperlipidemia, the highest prevalence was found for RFM ≥27 % (39.9 %) and the lowest prevalence for BMI ≥30 kg/m^2 (7.3 %). Significant differences were found between RFM ≥ 27 % and BMI ≥ 25 kg/m^2 ($p = 0.029$) and in all the remaining comparisons ($p < 0.001$). For H-CVR, the highest prevalence was found for RFM ≥27 % (65.7 %) and the lowest prevalence for BMI ≥30 kg/m^2 (12.4 %), with statistically significant differences among all four groups (p < 0.001).

Table 1
Main characteristics of study participants according to sex.

	Women ($n = 1077$)	Men ($n = 913$)	Total sample ($n = 1990$)	*p*
Age, years	72.8 (6.0)	73.5 (6.1)	73.2 (6.0)	0.014
Active smoking	147 (13.6 %)	147 (16.1 %)	294 (14.8 %)	0.144
Physically active	556 (51.6 %)	499 (54.7 %)	1055 (53.0 %)	0.322
Healthy diet	802 (74.5 %)	629 (68.9 %)	1431 (71.9 %)	0.006
Hypertension	677 (62.9 %)	686 (75.1 %)	1363 (68.5 %)	<0.001
Diabetes	136 (12.6 %)	173 (18.9 %)	309 (15.5 %)	<0.001
Hyperlipidemia	746 (69.3 %)	483 (52.9 %)	1229 (61.8 %)	<0.001
H-CVR	945 (87.7 %)	806 (88.3 %)	1751 (88.0 %)	0.766
BMI, kg/m^2	25.5 (4.3)	26.4 (3.4)	25.9 (3.9)	<0.001
Underweight (<18.5 kg/m^2)	27 (2.5 %)	2 (0.2 %)	29 (1.5 %)	<0.001
Overweight (25.0–29.9 kg/m^2)	378 (35.1 %)	456 (49.9 %)	834 (41.9 %)	0.367
Obese (≥30 kg/m^2)	156 (14.5 %)	116 (12.7 %)	272 (13.7 %)	0.266
RFM	39.7 (5.2)	29.0 (3.7)	34.8 (7.0)	<0.001

Data are reported as absolute numbers (percentages) for categorical variables (active smoking, physical activity, hypertension, diabetes, hyperlipidemia, underweight, overweight, obesity). Continuous variables are shown as means (standard deviations). Physically active: engaged in physical activity at least twice weekly for a minimum of 30 min per session during the previous year. Healthy diet: eating 3 or more portions of fruit and/or vegetables per day. Abbreviation: BMI: body mass index; H-CVR: heightened cardiovascular risk (at least two of the following: hypertension, diabetes, hyperlipidemia).

In female participants (Table 3), those with RFM ≥40 % and BMI ≥25 kg/m^2 showed the highest prevalence of hypertension (37.7 % for RFM ≥40 %, 36.1 % for BMI ≥25 kg/m^2, $p = 0.475$), diabetes (8.2 % for RFM ≥40 %, 7.2 % for BMI ≥25 kg/m^2, $p = 0.467$), hyperlipidemia (35.4 % for RFM ≥40 %, 35.1 % for BMI ≥25 kg/m^2, $p = 0.928$), and H-CVR (47.3 % for RFM ≥40 %, 46.0 % for BMI ≥25 kg/m^2, $p = 0.574$). Participants having BMI ≥30 kg/m^2 showed the lowest prevalence of hypertension (11.4 %, $p < 0.001$), diabetes (3.0 %, p < 0.001), hyperlipidemia (9.0 %, $p < 0.001$), and H-CVR (13.7 %, p < 0.001).

With regard to inter-rater reliability, participants with high RFM and BMI ≥25 kg/m^2 showed 78 % agreement (kappa = 0.571). After combining the presence of high RFM or BMI ≥25 kg/m^2 with each CRF, 85 % agreement was found for hypertension (kappa = 0.686), 97 % for diabetes (kappa = 0.837), 87 % for hyperlipidemia (kappa = 0.700), and 81 % for H-CVR (kappa = 0.628).

In males, RFM ≥27 % had the highest Youden index for hypertension and H-CVR (Table 2). In females, RFM ≥40 % had the highest Youden index for hypertension, diabetes, and H–CVR (Table 3).

Table 4 shows the association between CRFs and high adiposity defined as RFM ≥27 % in males and ≥ 40 % in females. In the unadjusted logistic regression model, high adiposity was significantly associated with higher ORs of hypertension (OR 2.89, 95 % CI 2.38–3.51, $p < 0.001$), diabetes (OR 2.77, 95 % CI 2.07–3.78, p < 0.001), and H-CVR (OR 2.57, 95 % CI 1.96–3.40, p < 0.001), but not with hyperlipidemia (OR 1.01, 95 % CI 0.84–1.21, $p = 0.999$). The association remained significant after adjusting for age and sex (Model 1: hypertension: OR 2.55, 95 % CI 2.09–3.12, $p < 0.001$; diabetes: OR 2.45, 95%CI 1.81–3.36, p < 0.001; H-CVR: OR 2.62, 95 % CI 1.97–3.49, p < 0.001) and other potential confounders (Model 2: hypertension: OR 2.47, 95% CI 2.02–3.04, p < 0.001; diabetes: OR 2.27, 95%CI 1.67–3.12, p < 0.001; H-CVR: OR 2.47, 95%CI 2.02–3.04, p < 0.001). For hypertension, older age was associated with increased OR in both Model 1 (OR 1.05, 95 % CI 1.03–1.07, $p < 0.001$) and Model 2 (OR 1.05, 95 % CI 1.03–1.07, p < 0.001). On the other hand, female sex was associated with lower odds of hypertension in both Model 1 (OR 0.68, 95 % CI 0.56–0.84, $p < 0.001$) and Model 2 (OR 0.67, 95 % CI 0.55–0.83, p < 0.001). A similar relationship was observed for diabetes both for age (Model 1: OR 1.04, 95 % CI 1.02–1.06, p < 0.001; Model 2: OR 1.04, 95 % CI 1.01–1.06, p < 0.001) and female sex (Model 1: OR 0.71, 95 % CI 0.55–0.92, $p = 0.010$; Model 2: OR 0.68, 95 % CI 0.52–0.89, $p = 0.005$). For hyperlipidemia, female sex (Model 1: OR 2.10, 95 % CI 1.74–2.53, p < 0.001; Model 2: OR 2.19, 95 % CI 1.81–2.66, p < 0.001) and active smoking (OR 1.41, 95 % CI 1.08–1.86, $p = 0.012$) were associated with higher odds. Older age was associated with increased OR of hyperlipidemia in Model 2 (OR 1.02, 95 % CI 1.00–1.03, $p = 0.036$), but not in Model 1 (OR 1.01, 95 % CI 0.96–1.03, $p = 0.066$). For H-CVR, age was associated with increased odds only in the fully adjusted model (Model 1: OR 1.02, 95 % CI 0.99–1.04, $p = 0.200$; Model 2: OR 1.05, 95 % CI 1.03–1.07, p < 0.001). Female sex was associated with lower OR in Model 2 (OR 0.67, 95 % CI 0.55–0.83, p < 0.001) but not in Model 1 (OR 1.19, 95 % CI 0.89–1.57, $p = 0.002$). No further associations were observed.

4. Discussion

In the present study, we evaluated the ability of RFM and BMI in predicting the presence of hypertension, diabetes, hyperlipidemia, and the co-occurrence of at least two CRFs in a large cohort of Italian community-dwelling older adults. We calculated the RFM threshold that identified individuals with H-CVR and compared it with different BMI cutoffs. ROC curve analysis demonstrated that RFM was a better predictor of hypertension in females and of diabetes in both sexes, while

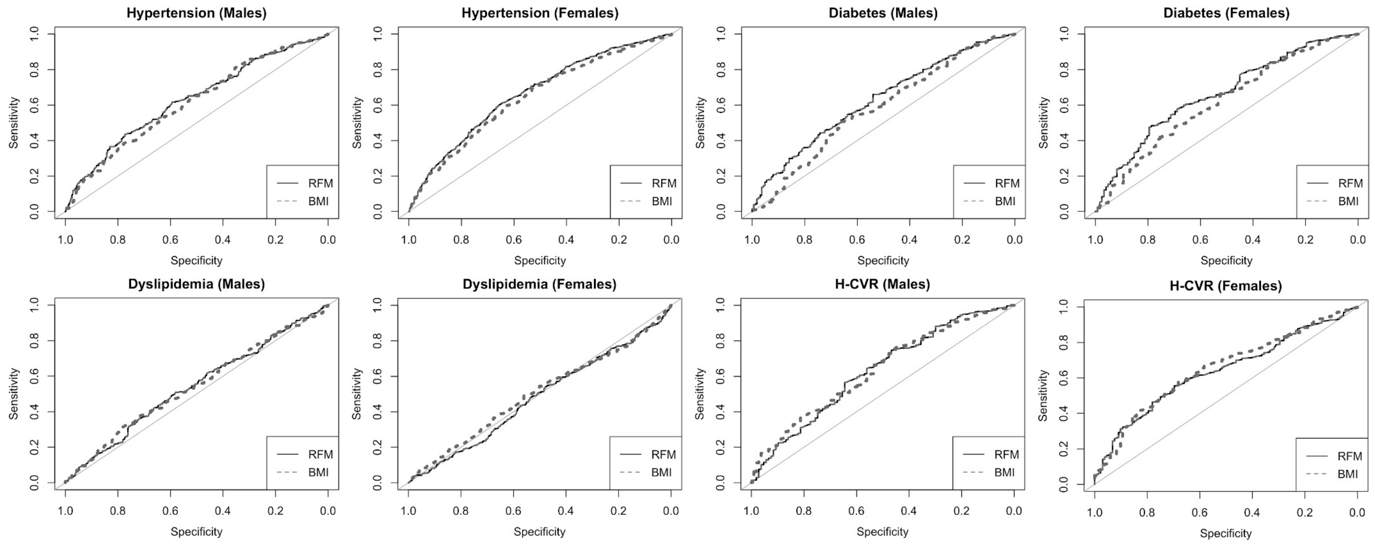

Fig. 2. Comparison of receiver operating (ROC) curves evaluating RFM and BMI for predicting hypertension, diabetes, hyperlipidemia, and the presence of at least two cardiovascular risk factors in males and females. Abbreviations: AUC: area under the curve; BMI: body mass index; H-CVR: heightened cardiovascular risk (at least two of the following: hypertension, diabetes, hyperlipidemia); RFM: relative fat mass.

Table 2
Predictive performance of cutoffs of relative fat mass and body mass index in male participants.

Males (n = 913)							
	Cutoff	Prevalence	Sensitivity	Specificity	Youden index (95 % CI)	AUC (95 % CI)	*p* (DeLong)
Hypertension							
RFM	$\geq$27 %	529 (57.9 %)	77.1 %	43.6 %	0.207 (0.108–0.305)	0.629	0.286
	$\geq$30 %	311 (34.1 %)	45.3 %	69.6 %	0.149 (0.047–0.247)		
BMI	$\geq$25 kg/m^2	455 (49.8 %)	66.3 %	48.5 %	0.148 (0.045–0.250)	0.614	
	$\geq$30 kg/m^2	100 (11.0 %)	93.0 %	14.6 %	0.075 (0.008–0.134)		
Diabetes							
RFM	$\geq$27 %	137 (15.0 %)	84.0 %	30.7 %	0.147 (0.049–0.234)	0.628	0.004
	$\geq$30 %	90 (9.9 %)	55.2 %	61.3 %	0.165 (0.050–0.278)		
BMI	$\geq$25 kg/m^2	117 (12.8 %)	71.8 %	39.3 %	0.111 (0.0003–0.215)	0.582	
	$\geq$30 kg/m^2	35 (3.8 %)	89.2 %	21.5 %	0.107 (0.022–0.199)		
Hyperlipidemia							
RFM	$\geq$27 %	364 (39.9 %)	75.4 %	31.9 %	0.072 (−0.013–0.156)	0.541	0.934
	$\geq$30 %	218 (23.9 %)	45.1 %	62.3 %	0.075 (−0.018–0.166)		
BMI	$\geq$25 kg/m^2	318 (34.8 %)	65.8 %	40.9 %	0.068 (−0.023–0.158)	0.542	
	$\geq$30 kg/m^2	67 (7.3 %)	13.8 %	88.6 %	0.075 (−0.039–0.087)		
H-CVR							
RFM	$\geq$27 %	600 (65.7 %)	74.4 %	46.7 %	0.212 (0.083–0.340)	0.628	0.745
	$\geq$30 %	349 (38.2 %)	43.3 %	71.0 %	0.143 (0.013–0.262)		
BMI	$\geq$25 kg/m^2	522 (57.2 %)	64.8 %	53.3 %	0.180 (0.047–0.310)	0.634	
	$\geq$30 kg/m^2	113 (12.4 %)	14.0 %	97.2 %	0.112 (0.037–0.160)		

Prevalence rates are reported as absolute numbers (percentages). Abbreviations: AUC: area under the curve; BMI: body mass index; CI: confidence interval; H-CVR: heightened cardiovascular risk (at least two of the following: hypertension, diabetes, hyperlipidemia); RFM: relative fat mass.

BMI was a better predictor only of hyperlipidemia in females. Non-inferiority of RFM was observed for other CRFs, compared to BMI. Moderate agreement was found between high adiposity or BMI $\geq$25 kg/m^2 combined with hypertension, hyperlipidemia and H-CVR, while a strong agreement was found in combination with diabetes.

Excess body fat accumulation, impaired glucose tolerance and diabetes, hyperlipidemia, and hypertension are a cluster of abnormalities defining metabolic syndrome (MS) [33]. While the role of visceral obesity in the MS pathophysiology is well established [34], the definition of the adiposity parameter has remained controversial [35,36]. Although BMI is easy to use for both physicians and patients, it cannot distinguish between lean and fat mass or take into consideration body fat distribution, especially in older adults [37]. According to findings in the LIPIDOGRAM cohort, MS patients with normal BMI (<25 kg/m^2) had a comparable 10-year death risk as those with overweight/obese BMI ($\geq$25 kg/m^2) [38]. In the same cohort, similar mortality rates were observed in MS participants with and without BMI-defined obesity [39]. Although WC has shown to be a better predictor of CVD than BMI [40], it has limitations related to the need to use sex- and ethnic-specific values, besides being less intuitive [41]. Based on these observations, Kobo et al. suggested the use of RFM as a better estimator of MS in the general population [42]. In a large sample of 20,167 individuals, RFM identified a larger proportion of individuals suffering from MS, with much more similar metabolic characteristics between males and females compared with WC [42]. In another study based on the same population, RFM provided a higher predictability of hyperlipidemia and MS compared with BMI [43]. Efe et al. identified RFM as a more reliable marker of central obesity for predicting the severity of coronary artery disease in idividuals $\geq$60 years old [44]. A subanalysis on the PARADIGM-HF cohort found that RFM or waist-to-hip ratio was related with a higher

Table 3

Predictive performance of cutoffs of relative fat mass and body mass index in female participants.

Females (n = 1077)							
	Cutoff	Prevalence	Sensitivity	Specificity	Youden index (95 % CI)	AUC (95 % CI)	*p* (DeLong)
Hypertension							
RFM	≥40 %	406 (37.7 %)	60.0 %	64.5 %	0.245 (0.158–0.329)	0.665	0.049
BMI	≥25 kg/m^2	389 (36.1 %)	57.5 %	63.7 %	0.212 (0.125–0.297)	0.643	
	≥30 kg/m^2	123 (11.4 %)	18.2 %	91.8 %	0.099 (0.039–0.155)		
Diabetes							
RFM	≥40 %	88 (8.2 %)	72.1 %	51.3 %	0.235 (0.114–0.344)	0.663	0.010
BMI	≥25 kg/m^2	78 (7.2 %)	63.9 %	52.3 %	0.162 (0.038–0.279)	0.618	
	≥30 kg/m^2	32 (3.0 %)	26.2 %	87.0 %	0.132 (0.034–0.240)		
Hyperlipidemia							
RFM	≥40 %	381 (35.4 %)	51.1 %	49.5 %	0.006 (−0.086–0.098)	0.481	0.041
BMI	≥25 kg/m^2	378 (35.1 %)	50.7 %	52.9 %	0.004 (−0.056–0.127)	0.503	
	≥30 kg/m^2	97 (9.0 %)	13.0 %	82.2 %	−0.048 (−0.117–0.178)		
H-CVR							
RFM	≥40 %	509 (47.3 %)	53.9 %	70.5 %	0.243 (0.125–0.352)	0.637	0.383
BMI	≥25 kg/m^2	495 (46.0 %)	52.4 %	70.5 %	0.228 (0.110–0.337)	0.651	
	≥30 kg/m^2	148 (13.7 %)	15.7 %	93.9 %	0.096 (0.018–0.155)		

Prevalence rates are reported as absolute numbers (percentages). Abbreviations: AUC: area under the curve; BMI: body mass index; CI: confidence interval; H-CVR: heightened cardiovascular risk (at least two of the following: hypertension, diabetes, hyperlipidemia); RFM: relative fat mass.

Table 4

Unadjusted and adjusted association between high body adiposity and cardiovascular risk factors.

Characteristics	Unadjusted OR (95 % CI)	*p*	Model 1 OR (95 % CI)	*p*	Model 2 OR (95 % CI)	*p*
Hypertension	2.89 (2.38–3.51)	<0.001	2.55 (2.09–3.12)	<0.001	2.47 (2.02–3.04)	<0.001
Diabetes	2.77 (2.07–3.78)	<0.001	2.45 (1.81–3.36)	<0.001	2.27 (1.67–3.12)	<0.001
Hyperlipidemia	1.01 (0.84–1.21)	0.999	1.16 (0.96–1.41)	0.120	1.20 (0.99–1.47)	0.068
H-CVR	2.57 (1.96–3.40)	<0.001	2.62 (1.97–3.49)	<0.001	2.47 (2.02–3.04)	<0.001

High body adiposity: relative fat mass ≥ 40 % in women and ≥27 % in men. Model 1: odds ratio adjusted for age and female sex; model 2: odds ratio adjusted for age, female sex, active smoking, healthy diet (eating 3 or more portions of fruit and vegetables/day), and engagement in physical activity. Abbreviations: CI: confidence interval; H-CVR: heightened cardiovascular risk (at least two of the following: hypertension, diabetes, hyperlipidemia); OR: odds ratio.

risk of hospitalization in patients with heart failure with reduced ejection fraction, whereas BMI was not [19]. Contrary to the notion of the “obesity paradox”, the latter studies highlight that older adults with excessive body fat may have worse outcomes when examined using anthropometric indices that take into account more than just body weight [19,44].

Based on Youden index, RFM rounded thresholds of ≥27 % in men and ≥40 % in women identified participants having H-CVR and were better predictors of hypertension, diabetes, and the concurrence of at least two CRFs. While the threshold for female participants was the same as the one calculated by Woolcott and Bergman [31], the cutoff for male participants was lower than 30 %. In 2002, Davinson et al. [45] developed an equation to estimate fat mass percentage based on WC, hip circumference, triceps skinfold, and sex using data from 2917 men and women 70 years older, of mixed ethnicity. Identified thresholds to predict the risk of mobility limitation identified in the validation study were 36.2 ± 3.8 % for women and 20.5 ± 3.3 % for men [45]. Using other sex-specific formulas based on BMI and other variables such as age and ethnicity, Gallagher et al. identified ≤43 % for women and ≤ 31 % in men as healthy fat mass percentages for Caucasians in the 60–79 age group, with lower values for both Asians and African Americans [46]. Pedrero-Chamizo et al. found that BIA-estimated fat mass values ≥40.9 % in women and ≥ 30.33 % in men were associated with lower physical fitness and worse health-related quality of life in older adults with sarcopenic obesity [47]. It is worth noting that, despite minor differences, the various cutoffs for defining a “healthy” fat percentage in older adults obtained through different methods are relatively comparable and correlate with several outcomes, such as functionals limitation, incidence and severity of CVD, and mortality. This reflects the complex interrelationship among body composition, physical performance, and metabolic and cardiovascular health [48,49]. Therefore, RFM could be one possible metric to adopt to identify complex conditions such as MS and sarcopenic obesity, not only in the context of individual outpatient assessment, but also in the broader framework of cardiovascular, metabolic, or disability risk assessment (e.g., the Moli-sani cardiovascular risk score [50]). Within cardiovascular and geriatric medicine, anthropometric measures that are not dependent on body weight may gain considerable significance due to the growing reliance on data-driven approaches [51,52].

A significant finding from our study is that individuals with a BMI ≥30 mg/kg^2 or a RFM ≥30 % showed a lower prevalence of unfavorable cardiovascular health metrics and H-CVR. This suggests that overly restrictive threshold values in a population already having a higher prevalence of CRFs [4] might miss many of those with lower BMI or RFM, but considerable metabolic and cardiovascular risk. This issue was previously highlighted by Pan et al. [53], who therefore advocated adopting lower BMI cut-offs to identify individuals with metabolic complications. Furthermore, the threshold values for both RFM and BMI showed relatively low sensitivity and specificity when used as the only predictors of cardiovascular risk. This underscores the potential limitations of relying solely on BMI and RFM for assessing cardiovascular risk in older adults. The complexity of cardiovascular risk assessment in old individuals necessitates a more comprehensive approach that extends beyond simple anthropometric measurements. Future models incorporating anthropometric measures with additional risk factors could provide a higher predictive accuracy of cardiovascular risk assessment in old age, offering more effective tools for managing cardiovascular prevention in this population.

While the current study reports intriguing findings, it is important to acknowledge its inherent limitations. The cross-sectional design hinders the possibility to observe potential prospective correlations between body adiposity and health outcomes. Second, a considerable proportion of participants were excluded from the analysis due to incomplete data. Despite efforts to limit assessment durations to a tolerable extent, individuals were tested while engaging in retail activities or attending social events. Participants often choose to end the assessment before all the data were collected. Nevertheless, the key characteristics of individuals with missing data were not different from those included in the study. Additionally, the large sample size mitigated the impact of participant exclusion on the reliability of the findings. Third, while current research suggests that the Woolcott and Bergman equation offers consistent RFM estimations across ages and ethnic groups, it is not a direct measure of body fat. Nonetheless, RFM was demonstrated to be a reliable predictor of DXA-measured whole-body fat percentage [23]. Moreover, RFM has recently been included in the Moli-sani risk score [48], a validated algorithm for estimating the impact of modifiable risk factors on cardiovascular risk. Fourth, in our study total blood cholesterol was used as the parameter to define hyperlipidemia. Although both European and American guidelines emphasize the importance of managing low-density and high-density lipoprotein cholesterol in preventing cardiovascular disease risk [54,55], current evidence indicates a correlation between elevated total serum cholesterol and an increased risk of cardiovascular death [56,57]. Fifth, information regarding specific medications or medical conditions was not available. Conducting a thorough medical history collection would substantially increase the duration of the assessments, making them inappropriate for the nontraditional settings in which the research was carried out. Further research is required to address this limitation and examine the influence of clinical variables on body adiposity. Sixth, virtually all participants were Caucasians; thereby, results may not be applicable to other ethnicities. Seventh, our study only included older adults living in the community; therefore, findings may not be generalizable to other settings. Eighth, no socioeconomic characteristics were collected in our investigation. It is widely recognized that individuals facing socioeconomic disparities are more likely to encounter CRFs such as hypertension, diabetes, high cholesterol, and obesity [58]. Moreover, socioeconomical vulnerability, lower income, and limited educational opportunities significantly affect the willingness of individuals to participate in health screening campaigns [59]. To limit barriers to participation, all check-ups were offered at no cost during events with open access and in locations freely accessible to the public. Additionally, as noted earlier, our study took place in cities of different sizes and various districts within larger urban areas to ensure a broad representation of sociodemographic features.

The present study demonstrates non-inferiority of RFM compared with BMI in detecting individuals at H-CVR, as evidenced by the AUC comparisons. We further established that RFM thresholds, identified through the Youden index, may serve as more reliable markers than traditional BMI thresholds for recognizing individuals at H-CVR. Our findings support the role of anthropometric measures in evaluating body composition and their metabolic and cardiovascular complications in older adults.

Contributors

Stefano Cacciatore participated in conceptualization, methodology, formal analysis, investigation, and writing the original draft.

Riccardo Calvani participated in conceptualization, methodology, formal analysis, writing the original draft, and review and editing.

Emanuele Marzetti participated in conceptualization, review and editing, and funding acquisition.

Helio José Coelho-Júnior participated in methodology and validation.

Anna Picca participated in validation.

Alberto Emanuele Fratta participated in investigation.

Ilaria Esposito participated in methodology.

Matteo Tosato participated in validation.

Francesco Landi participated in conceptualization, funding acquisition, supervision.

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Ethical approval

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Università Cattolica del Sacro Cuore, Rome, Italy (protocol #A.1220/CE/2011).

Informed consent was obtained from all subjects involved in the study.

Provenance and peer review

This article was not commissioned and was externally peer reviewed.

Research data (data sharing and collaboration

There are no linked research data sets for this paper. The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to their containing information that could compromise the privacy of the research participants.

Declaration of competing interest

The authors declare that they have no competing interest.

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