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ORIGINAL ARTICLE

Arterial Stiffness in Overweight and Obesity: Association with Sex, Age, and Blood Pressure

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Abstract

Introduction Obesity has been associated with increased arterial stiffness. Sex-differences in arterial stiffness in obesity have been less explored.

Aim To explore sex-differences in arterial stiffness by applanation tonometry in 323 women and 225 with overweight and obesity, free of cardiovascular disease.

Methods Covariables of arterial stiffness were identified in multivariable linear regression analyses in the total cohort and separately in women and men.

Results In the total study cohort, women had higher augmentation pressure (AP) and augmentation index (AIx), and lower carotid-femoral pulse wave velocity (cf-PWV) than men, independent of confounders (all $p < 0.001$). In sex-specific analyses, higher AP was associated with higher age and 24-hours systolic blood pressure (BP), and with lower heart rate in women (all $p < 0.001$), and with higher age and BP in men (all $p < 0.001$). Similarly, higher AIx was associated with higher age and BP, and lower body mass index (BMI) and heart rate in women (all $p < 0.05$), and with higher age in men (all $p < 0.001$). Higher cf-PWV correlated with higher age and BP in women (all $p < 0.005$), and additionally with higher heart rate and non-smoking in men (all $p < 0.05$). When replacing BMI with waist-hip ratio, higher waist-hip ratio was associated with higher cf-PWV in men only ($p < 0.05$).

Conclusions Among subjects with overweight and obesity, AP and AIx were higher in women, and cf-PWV was higher in men. Age and 24-hours systolic BP were the main factors associated with arterial stiffness in both sexes, while measures of adiposity had little impact on arterial stiffness.

Keywords Obesity · Arterial stiffness · Sex · Augmentation index · Pulse wave velocity

1 Introduction

Arterial stiffness increases in parallel with presence of known cardiovascular (CV) risk factors, in particular age and systolic blood pressure (BP), in both women and men [1–3]. There are several methods to assess arterial stiffness, and well-known sex differences between these measures. While the gold standard measure of arterial stiffness, carotid-femoral pulse wave velocity (cf-PWV), is higher in men, other measures like augmentation pressure (AP) and augmentation index (AIx) are higher in women [1, 4]. Among participants with normal BP and body mass index (BMI) in the Framingham Heart Study, women had a lower cf-PWV compared to men up to 70 years of age [2]. Furthermore, in a subset of 4001 healthy participants aged 18–90 years in the Anglo-Cardiff Collaborative Trial, AP and AIx were higher in women compared to men regardless of age, while no sex difference in cf-PWV was found [1].

Obesity leads to chronic CV inflammation and has been associated with increased arterial stiffness [5]. Both prevalence of obesity and adipose tissue distribution differ between women and men [6–9]. Previous studies of sex differences in arterial stiffness in overweight or obese individuals have found diverging results. In a Dutch population based study, higher BMI was associated with higher

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cf-PWV only in women, while higher waist circumference and waist-height ratio were associated with higher cf-PWV only in men [10]. In subjects with hypertension and overweight, abdominal adiposity measured by waist–hip ratio and waist-height ratio were associated with higher cf-PWV in both sexes [11]. However, while these previous studies on arterial stiffness in obesity mostly focused on cf-PWV [10, 12], there is less knowledge about how obesity influences other measures of arterial stiffness like AP and AIx. The aim of the current study was to explore covariates of different measures of arterial stiffness among women and men with increased BMI in the FAT associated CardiOvasculaR dysfunction (FATCOR) study.

2 Methods

2.1 Study Population

The FATCOR study was performed from 2009 to 2017 in Bergen, Norway as a collaboration between a general practitioner center specialized in the management of obese patients and the Department of Heart Disease, Haukeland University Hospital. Women and men aged 30–65 years with a BMI >27.0 kg/m^2 were recruited after advertisement in a local newspaper and screened by a general practitioner [13]. Exclusion criteria were history of myocardial infarction, gastrointestinal disorders, severe psychiatric illness, or the inability to communicate in Norwegian language. A total number of 620 participants were recruited. For the present analysis, participants who withdrew consent (n = 2), or with incomplete recording of cf-PWV (n = 24), pulse wave analysis (n = 26), and 24-hours (24-h) systolic BP (n = 55) were excluded, leaving 323 women and 225 men eligible for analysis.

2.2 Compliance with Ethical Standards

The FATCOR study was approved by the Regional Ethics Committee (approval number 17173) and complied with the Declaration of Helsinki. All participants signed written informed consent.

2.3 Cardiovascular Risk Factors

Self-reported information about general health, including use of medication, was collected in a standardized questionnaire. The information was quality assured against medical hospital records by a study nurse. BMI was calculated as body weight in kilograms/body height in meters squared (kg/m^2). Obesity was defined as BMI ≥30 kg/m^2. Waist and hip circumferences were measured as recommended by the WHO using a nonflexible measuring tape [14]. Waist–hip ratio was calculated as waist circumference/hip circumference, and waist-height ratio as waist circumference/body height, all measured in centimeters. Tetrapolar bioelectrical impedance analysis (Tanita-TBF-300A, Tanita Corporation of America, Arlington Heights, USA) was used to analyze body composition. Blood glucose and lipids were measured in fasting, venous blood samples. Diabetes mellitus was considered present if history of diabetes mellitus, fasting blood glucose ≥7 mmol, 2-hours plasma glucose ≥11.1 mmol/l during oral glucose tolerance test (OGTT), or glycated hemoglobin A1C (HbA_{1c}) ≥6.5% [15]. Estimated glomerular filtration rate (eGFR) was calculated using the equation from the Chronic Kidney Disease Epidemiology Collaboration [16]. Smoking was defined as current smoking. High-sensitive C-reactive protein (hs-CRP) was measured in serum by Matrix-Assisted Laser Desorption/Ionization Time-Of-Flight mass spectrometry.

2.4 Blood Pressure Measurement

BP was measured by a study nurse at the general practitioner's office. Attended BP and heart rate were measured three times with 1 min intervals after 5 min initial rest in the sitting position, using a regularly calibrated digital automatic Omron M4 sphygmomanometer (Omron Healthcare Co. Ltd., Hoofdorp, The Netherlands) and an appropriate cuff size on the non-dominant arm [17]. Clinical BP and heart rate were calculated as the average of the last 2 measurements. 24-h ambulatory BP was recorded using a Diasys Integra II apparatus (Novacor, Cedex, France). BP was recorded every 20 minutes during daytime and every 30 minutes during nighttime with an appropriately sized cuff on the non-dominant arm. Participants were instructed to avoid hard exercise and to relax their arm while the apparatus was measuring, but otherwise engage in normal activities [17]. The 24-h BP recording was repeated if <70% of measurements were valid. Hypertension was considered present if the participant reported use of antihypertensive drugs or had elevated 24-h BP (average 24-h systolic BP ≥130 mmHg or average 24-h diastolic BP ≥80 mmHg) [18].

2.5 Arterial Stiffness

Arterial stiffness was assessed by AP, AIx, and cf-PWV by using applanation tonometry (SphygmoCor, AtCor Medical, Sydney, West Ryde, Australia) under standardized laboratory conditions in accordance with guidelines [4]. Carotid pulse wave analysis was used to estimate AP and AIx. Pulse pressure waveforms were acquired transcutaneously from the right common carotid and femoral arteries with simultaneous recordings of the electrocardiograms to synchronize times for carotid and femoral pulse waves. Cf-PWV was calculated as the distance in meters between the two recording sites divided by the transit time between the recording sites in seconds [4].

2.6 Statistics

Statistical analyses were performed using the IBM SPSS version 28 (IBM, Armonk, New York, USA). Continuous variables are presented as means ± standard deviations, and categorical variables are presented as numbers and percentages. hs-CRP was not normally distributed in the cohort, and therefore presented as median and interquartile range in the total cohort and in groups of women and men, and log transformed before included in statistical analyses. In group comparison, the Student's t-test was used for continuous variables and the Chi-square test was used for categorical variables. Factors associated with AP, AIx, and cf-PWV were identified in univariable linear regression in the total study cohort and in sex-specific analyses, and significant covariates were included in multivariable models. The multivariable models on AP and AIx were adjusted for sex, age, BMI, 24-h systolic BP, heart rate, and smoking. Multivariable models on cf-PWV were additionally adjusted for diabetes mellitus. In secondary models, BMI was replaced by waist–hip ratio, fat mass percentage, waist circumference, waist-height ratio, and obesity as a categorical variable. Results were reported as standardized β-coefficients and p-values. In all analyses, a p-value<0.05 was considered statistically significant.

3 Results

3.1 Characteristics of the Total Study Population and Groups of Women and Men

Clinical characteristics and data on arterial stiffness are presented in Table 1. In this middle-aged population, women had higher mean AP and AIx compared to men, while men had higher mean cf-PWV than women (all $p < 0.001$) (Table 1) (Fig. 1). Women also had higher BMI, fat mass percentage, hip circumference, waist-height ratio, and heart rate than men (all $p < 0.05$). Men had higher waist circumference, waist-hip ratio, 24-h systolic BP and 24-h diastolic BP values, and higher prevalence of hypertension (all $p < 0.001$). Prevalence of obesity, diabetes mellitus, smoking, and mean eGFR did not differ by sex (all p>0.05).

3.2 Factors Associated with Arterial Stiffness in the Total Study Population

Results from univariable analyses are presented in Table 2. In multivariable analyses, women had higher AP ($\beta = 0.41$) and AIx ($\beta = 0.48$) compared to men, independent of age, BMI, 24-h systolic BP, heart rate, and smoking (all $p < 0.05$) (Table 2). Men had higher cf-PWV ($\beta = 0.16$) compared to women, independent of age, BMI, 24-h systolic BP, heart rate, diabetes mellitus, and smoking (all $p < 0.001$).

3.3 Factors Associated with Arterial Stiffness in Women

Results from univariable analysis are presented in Table 3. In multivariable analysis in women, higher AP was associated with higher age and 24-h systolic BP, and lower heart rate (all $p < 0.001$) (Table 3). Higher AIx was associated with higher age and 24-h systolic BP, and lower BMI and heart rate (all $p < 0.05$). In the same model, when BMI was replaced by obesity as a dichotomous variable, obesity was not significantly associated with AIx in women (data not shown). Higher cf-PWV was associated with higher age and 24-h systolic BP (all $p < 0.001$). Measures of adiposity, including BMI, obesity, waist-hip ratio, fat mass percentage, waist circumference, and waist-height ratio were not significantly associated with cf-PWV in women (all $p > 0.05$) (Table 4).

3.4 Factors Associated with Arterial Stiffness in Men

In multivariable analysis in men, higher AP was associated with higher age and 24-h systolic BP (both $p < 0.001$), while higher AIx was associated with higher age only ($p < 0.001$) (Table 3). Higher cf-PWV was associated with higher age, 24-h systolic BP, heart rate, and with non-smoking habit (all $p < 0.05$). Among measures of adiposity, higher cf-PWV was associated with higher waist–hip ratio in men ($p < 0.05$) (Table 4) (Fig. 2), while no significant associations with BMI, obesity, fat mass percentage, waist circumference, or waist height-ratio were found (Table 4).

4 Discussion

This study adds important new knowledge on sex differences in arterial stiffness in overweight and obesity. Among subjects with overweight and obesity in the FATCOR study, women had higher AP and AIx, while cf-PWV was higher in men, independent of confounders. Increasing age and higher 24-h systolic BP were the main factors associated with higher arterial stiffness in both women and men, reflecting previous findings in healthy normal-weight cohorts [1, 2], while measures of adiposity seemed to have little impact on arterial stiffness in the present cohort.

Table 1 Characteristics of the study population

Variable	All (n = 548)	Women (n = 323)	Men (n = 225)	p-value
Age, years	48 ± 9	48 ± 9	47 ± 9	0.158
Weight, kg	96 ± 15	90 ± 15	103 ± 14	< 0.001
Height, cm	173 ± 9	167 ± 6	180 ± 7	< 0.001
BMI, kg/m^2	31.9± 4.1	32.2 ± 4.4	31.6 ± 3.6	0.035
Obese, n (%)	344 (63)	204 (63)	140 (62)	0.447
Fat mass, %	38 ± 8	43 ± 4	29 ± 5	< 0.001
Waist circumference, cm	108 ± 11	106 ± 12	111 ± 10	< 0.001
Hip circumference, cm	115 ± 12	118 ± 12	112 ± 9	< 0.001
Waist–hip ratio	0.94 ± 0.08	0.90 ± 0.07	0.99 ± 0.07	< 0.001
Waist-height ratio	0.62 ± 0.06	0.63 ± 0.07	0.61 ± 0.05	< 0.001
Clinic systolic BP, mmHg	130 ± 16	127 ± 17	134 ± 14	< 0.001
Clinic diastolic BP, mmHg	82 ± 9	81 ± 9	85 ± 10	< 0.001
24-h systolic BP, mmHg	121 ± 12	119 ± 12	124 ± 11	< 0.001
24-h diastolic BP, mmHg	79 ± 8	78 ± 7	82 ± 7	< 0.001
Central systolic BP, mmHg	116 ±15	115 ± 16	118 ± 13	0.007
Central diastolic BP, mmHg	80 ± 8	79 ± 8	82 ± 8	< 0.001
Central pulse pressure, mmHg	36 ± 10	36 ± 11	37 ± 9	0.225
Hypertension, n (%)	343 (65)	185 (59)	158 (73)	< 0.001
Use of anti-hypertensive drugs, n (%)	111 (21)	63 (20)	48 (22)	0.319
24-h heart rate, beats/min	75 ± 8	76 ± 8	73 ± 8	< 0.001
Heart rate, beats/min	68 ± 10	69 ± 10	66 ± 11	< 0.001
Aorta augmentation pressure, mmHg	10 ± 6.8	12 ± 6.4	8 ± 6.5	< 0.001
Aorta augmentation index, %	28 ± 14	33 ± 11	21 ± 15	< 0.001
Pulse wave velocity, m/s	7.5 ± 1.7	7.3 ± 1.6	7.8 ± 1.7	< 0.001
Diabetes mellitus, n (%)	58 (12)	34 (12)	24 (12)	0.537
LDL cholesterol, mmol/l	3.6 ± 0.9	3.6 ± 0.9	3.7 ± 1	0.317
HDL cholesterol, mmol/l	1.3 ± 0.3	1.4 ± 0.3	1.1 ± 0.3	< 0.001
eGFR, ml/min/1.73m^2	96 ± 13	96 ± 14	97 ± 12	0.071
Smoking, n (%)	66 (13)	36 (12)	30 (14)	0.279
hs-CRP, µg/mL	2.01 (0.93, 4.85)	2.10 (1.05, 5.06)	1.83 (0.76, 4.66)	0.289

BMI body mass index, *BP* blood pressure, *24-h* 24-hours, *LDL* low-density lipoprotein, *HDL* high-density lipoprotein, *eGFR* estimated glomerular filtration rate, *hs-CRP* high-sensitive C-reactive protein

4.1 Sex-Differences in Arterial Stiffness

Our finding that AP and AIx were higher in women, and cf-PWV was higher in men, are in line with previous large population-based studies in healthy, normotensive, non-obese subjects [2, 3, 19]. Prior to the current study, sex-specific information regarding arterial stiffness in obesity was scarce. In a small study of 133 morbidly obese patients, cf-PWV was higher in men than women, and increased in parallel with obesity severity in women, but not in men [20]. However, this study included a high number of patients with diabetes mellitus and coronary artery disease. Current European guidelines for assessment of arterial stiffness recommend use of cf-PWV and consider cf-PWV >10 m/s as a common threshold indicating increased arterial stiffness in both sexes [17]. Taken together, these results suggest that sex-specific thresholds for diagnosis of increased arterial stiffness may be considered when BMI is increased. This should be further tested in prospective outcome studies.

While cf-PWV is dependent on aortic wall stiffness and lumen diameter, AP and AIx are both measures of the peripheral wave reflection and express central pressure wave characteristics in the aorta [21, 22]. In specific, AIx is the proportion of central pulse pressure that is attributable to late systolic increase in pressure caused by overlap between the forward and reflected pressure wave [22]. It has been suggested that AIx is a better measure for arterial stiffness than cf-PWV in individuals under 50 years of age [1]. Still, few previous studies on arterial stiffness in obesity have included assessment of arterial stiffness by measures of peripheral wave reflection like AP and AIx. The Copenhagen City Heart Study found that age-group specific high AIx was significantly related to all-cause mortality in men but not in women, even after adjusting for CV risk factors such as BP

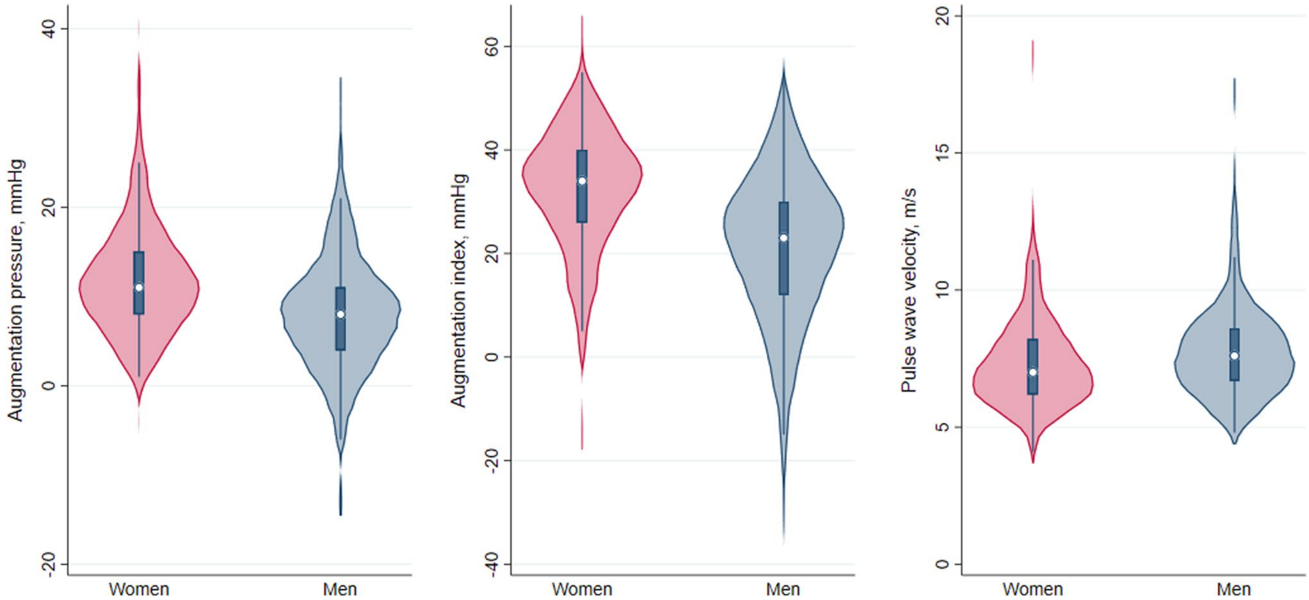

Fig. 1 Measures of arterial stiffness in women and men. Violin plot. The white dot marks the median and the blue bar in the center of the violin marks the interquartile range. The light red and light blue colored areas demonstrate distribution of data in women and men, respectively

Table 2 Associations of sex with arterial stiffness measures in linear regression analyses in the total study cohort

	Augmentation pressure				Augmentation index				Pulse wave velocity			
	Univariable		Multivariable		Univariable		Multivariable		Univariable		Multivariable	
	β	p-value	β	p-value	β	p-value	β	p-value	β	p-value	β	p-value
Male sex	−0.304	< 0.001	−0.409	< 0.001	−0.421	< 0.001	−0.480	< 0.001	0.146	0.001	0.163	< 0.001
Age, years	0.419	< 0.001	0.377	< 0.001	0.356	< 0.001	0.327	< 0.001	0.428	< 0.001	0.375	< 0.001
BMI, kg/m^2	−0.030	0.480	−0.036	0.335	−0.090	0.034	−0.084	0.029	0.065	0.128	0.059	0.164
24-h systolic BP, mmHg	0.271	< 0.001	0.315	< 0.001	0.074	0.086	0.145	< 0.001	0.296	< 0.001	0.167	< 0.001
Heart rate, beats/min	−0.041	0.348	−0.174	< 0.001	−0.022	0.618	−0.143	< 0.001	0.215	< 0.001	0.171	< 0.001
Diabetes mellitus	0.005	0.911			−0.019	0.675			0.136	0.002	0.022	0.536
Smoking	−0.048	0.276	−0.025	0.473	−0.009	0.839	0.008	0.830	−0.126	0.004	−0.133	< 0.001
hs-CRP, μg/mL	−0.021	0.631			−0.025	0.569			−0.003	0.953		

BMI body mass index, *24-h systolic BP* 24-hours systolic blood pressure, *hs-CRP* high-sensitive C-reactive protein

[23]. In the present study, higher age and 24-h systolic BP were the most important factors associated with higher AP in both sexes. Higher levels of 24-h systolic BP were strongly associated with AIx only in women, suggesting important sex-differences in BP related pulsative vascular load. This is in line with previous findings that young women are more prone to develop hypertension and associated complications in obesity compared to their male counterparts [24]. Furthermore, sex differences in pulsative vascular load may partly explain why hypertension is a stronger risk factor for heart disease in women compared to men [25].

Interestingly, lower BMI was associated with higher AIx in women in the current study. However, when adjusting for BMI as a dichotomous variable, obesity was not associated with AIx in women, nor in men. In contrast, a study in normotensive non-obese healthy men and women found that BMI, waist circumference, and waist-hip ratio were inversely associated with aortic AIx in women [26], after adjusting for confounders.

4.2 Association of Different Measures of Adiposity with Arterial Stiffness

Body fat distribution differ by sex [9]. Visceral adipose tissue is on both relative and absolute terms higher in men than in women, while the amount of subcutaneous adipose

Table 3 Sex-specific factors associated with arterial stiffness in linear regression analyses

	Augmentation pressure				Augmentation index				Pulse wave velocity			
	Univariable		Multivariable		Univariable		Multivariable		Univariable		Multivariable	
	β	p-value	β	p-value	β	p-value	β	p-value	β	p-value	β	p-value
Women												
Age, years	0.464	< 0.001	0.405	< 0.001	0.398	< 0.001	0.353	< 0.001	0.401	< 0.001	0.343	< 0.001
BMI, kg/m^2	−0.077	0.167	−0.035	0.466	−0.189	< 0.001	−0.133	0.014	0.035	0.536	0.060	0.306
24-h systolic BP, mmHg	0.424	< 0.001	0.369	< 0.001	0.219	< 0.001	0.193	< 0.001	0.315	< 0.001	0.191	0.001
Heart rate, beats/min	−0.153	0.006	−0.226	< 0.001	−0.161	0.004	−0.211	< 0.001	0.164	0.003	0.103	0.067
Diabetes mellitus	0.045	0.436			0.020	0.728			0.081	0.167	−0.028	0.614
Smoking	−0.100	0.084	−0.052	0.263	−0.052	0.371	−0.031	0.551	−0.131	0.023	−0.092	0.097
hs-CRP, µg/mL	−0.031	0.590			−0.096	0.096			0.001	0.991		
Men												
Age, years	0.372	< 0.001	0.383	< 0.001	0.353	< 0.001	0.376	< 0.001	0.492	< 0.001	0.423	< 0.001
BMI, kg/m^2	−0.019	0.772	−0.049	0.467	−0.069	0.303	−0.064	0.356	0.149	0.026	0.038	0.542
24-h systolic BP, mmHg	0.282	< 0.001	0.242	< 0.001	0.166	0.013	0.118	0.085	0.213	0.001	0.137	0.026
Heart rate, beats/min	−0.025	0.710	−0.108	0.104	−0.042	0.538	−0.106	0.123	0.343	< 0.001	0.265	< 0.001
Diabetes mellitus	−0.049	0.482			−0.065	0.354			0.212	0.002	0.080	0.187
Smoking	0.037	0.592	0.011	0.865	0.062	0.372	0.044	0.498	−0.133	0.053	−0.192	0.001
hs-CRP, µg/mL	−0.064	0.354			−0.027	0.693			0.017	0.804		

BMI body mass index, *24-h systolic BP* 24-hours systolic blood pressure, *hs-CRP* high-sensitive C-reactive protein

tissue is relatively higher in women [9]. Measures of obesity have been associated with arterial stiffness in both women and men in population-based studies [27, 28]. In a large Italian population-based study, an association between adiposity and cf-PWV was found in both sexes [27]. A Czech population-based study found that measures of abdominal adiposity such as waist circumference, waist-hip ratio, and waist-height ratio correlated better with cf-PWV than general adiposity measures such as BMI, even after adjusting for age, sex, mean arterial pressure, hypertension, diabetes mellitus, and dyslipidemia [29]. In a small Brazilian study in obese adults without diabetes mellitus, lower American Heart Association CV health life's essential 8 score (based on health behaviours and metabolic risk factors) was associated with higher AP, but not with cf-PWV [30]. However, lower score was associated with high-for-age cf-PWV, reflecting early vascular aging. Among overweight and obese participants in the current study, waist-hip ratio was the only measure of adiposity that was significantly associated with cf-PWV, but only in men. Taken together, these results may suggest that in a population with increased BMI, the level of obesity has less impact on arterial stiffness.

4.3 Other Confounders of Arterial Stiffness

Traditionally, office BP measurement has been used to identify hypertension, and most studies on arterial stiffness have reported office BP [1, 20]. The use of 24-h BP is advantageous in obesity because the prevalence of masked hypertension is greater than in the general population [31]. Furthermore, 24-h BP has a stronger association with CV organ damage compared to office BP [32]. Therefore, 24-h systolic BP was measured in the present study. As demonstrated, higher age and 24-h systolic BP were the main covariables of higher AP and cf-PWV both in women and men.

Higher heart rate was associated with higher cf-PWV in men. In contrast, among women, higher heart rate was associated with both lower AP and AIx. Earlier studies have demonstrated the same negative association between heart rate and AIx [33]. The lower AIx found with increasing heart rate may be explained by a reduction in ejection duration, causing a shift of the reflected pulse wave into diastole [33].

5 Study Limitations

Health information in the current study was self-reported, and even though the information was quality assured by a study nurse, health problems may have been underreported.

Volunteer bias is also possible as participants were recruited via advertisement in a local newspaper. The design of this study was cross-sectional, hence cause–effect relationship could not be confirmed, and future prospective longitudinal studies might therefore be necessary. The low prevalence of diabetes mellitus in the FATCOR study cohort

Table 4 Measures of adiposity associated with carotid-femoral pulse wave velocity in sex-specific multivariable analyses

	Pulse wave velocity											
	β	p-value	β	p-value	β	p-value	β	p-value	β	p-value	β	p-value
Women												
Age, years	0.343	< 0.001	0.322	< 0.001	0.302	< 0.001	0.325	< 0.001	0.329	< 0.001	0.338	< 0.001
BMI, kg/m^2	0.060	0.306										
Waist–hip ratio			0.057	0.320								
Fat mass, %					−0.072	0.214						
Waist, cm							−0.005	0.925				
Waist-height ratio									0.006	0.922		
Obesity											0.044	0.453
24-h systolic BP, mmHg	0.191	0.001	0.188	0.001	0.258	< 0.001	0.201	< 0.001	0.206	< 0.001	0.195	< 0.001
Heart rate, beats/min	0.103	0.067	0.115	0.040	0.099	0.085	0.110	0.051	0.101	0.076	0.106	0.058
Diabetes mellitus	−0.028	0.614	−0.018	0.753	−0.055	0.332	−0.033	0.556	−0.031	0.586	−0.027	0.633
Smoking	−0.092	0.097	−0.089	0.081	−0.059	0.300	−0.091	0.103	−0.087	0.121	−0.093	0.093
Men												
Age, years	0.423	< 0.001	0.390	< 0.001	0.408	< 0.001	0.415	< 0.001	0.414	< 0.001	0.418	< 0.001
BMI, kg/m^2	0.038	0.542										
Waist–hip ratio			0.128	0.043								
Fat mass, %					0.112	0.074						
Waist, cm							0.092	0.145				
Waist-height ratio									0.065	0.315		
Obesity											0.018	0.768
24-h systolic BP, mmHg	0.137	0.026	0.128	0.033	0.131	0.035	0.130	0.034	0.138	0.024	0.143	0.018
Heart rate, beats/min	0.265	< 0.001	0.250	< 0.001	0.228	< 0.001	0.248	< 0.001	0.253	< 0.001	0.270	< 0.001
Diabetes mellitus	0.080	0.187	0.080	0.185	0.106	0.088	0.078	0.194	0.077	0.204	0.080	0.187
Smoking	−0.192	0.001	−0.189	0.001	−0.193	0.001	−0.183	0.002	−0.182	0.002	−0.191	0.001

BMI body mass index, *24-h systolic BP* 24-hours systolic blood pressure

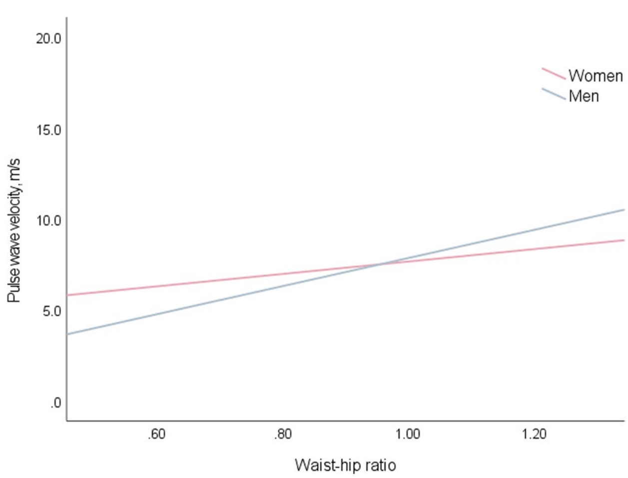

Fig. 2 Sex specific associations between waist-hip ratio and carotid-femoral pulse wave velocity (cf-PWV) in linear regression analyses. Slope women: 3.4 m/s (p = 0.006). Slope men: 7.7 m/s (p < 0.001)

precluded more detailed assessment of this important risk factor. The association of obesity-associated chronic CV inflammation with arterial stiffness could not be widely explored, since only data on hs-CRP was available for the present analysis. Performing bioelectrical analysis using foot-foot system may result in underestimation of the actual fat-free mass in subjects with increased BMI, and also result in underestimation and overestimation of body fat in men and women, respectively [34].

6 Conclusion

In the FATCOR study, including overweight and obese subjects without known CV disease, AP and AIx were higher in women, while cf-PWV was higher in men. The main factors associated with increased arterial stiffness in both sexes were higher age and 24-h systolic BP. Measures of adiposity had little impact on arterial stiffness among overweight and obese subjects in the present study.

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Declarations

Conflict of interest The authors have no conflict of interest.

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