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Association of pulse wave velocity with body fat measures at 30 y of age

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ABSTRACT

Objectives: Pulse wave velocity (PWV) is an early marker of arterial stiffness and a strong predictor of cardiovascular disease (CVD). Body fat measures, such as body mass index (BMI), waist circumference (WC), and visceral fat, have been associated with CVD in adulthood. The aim of this study was to evaluate the association of PWV at 30 y of age using body fat measures.
Methods: In 1982, the maternity hospitals in Pelotas, Brazil, were visited daily and all live births were identified. These infants have been prospectively followed several times. At 30 y, we tried to follow the cohort; the individuals were interviewed and had PWV, anthropometric parameters, abdominal fat, and visceral fat measured.
Results: The present study included 1576 individuals. PWV was highly correlated with BMI, WC, visceral fat thickness, and fat mass compared with other body composition measures. In linear regression analysis, the highest regression coefficients were observed for BMI ($r = 0.30$; 95% confidence interval [CI], 0.25–0.35), visceral fat thickness ($r = 0.30$; 95% CI, 0.24–0.35), and fat mass ($r = 0.30$; 95% CI, 0.24–0.35), even after controlling for potential confounders (sex, race, birth weight, family income, family education, and maternal smoking during pregnancy).
Conclusion: In the present study, BMI, visceral fat thickness, and fat mass were the strongest body fat measures related to PWV.

Introduction

In 2012, cardiovascular disease (CVD) was the leading cause of death among the non-communicable diseases (NCDs; 17.5 million deaths, or 46% of all deaths owing to non-communicable diseases) [1]. Among the multiple cardiovascular risk factors, obesity is one of the most important because it may increase the risk for other factors such as hypertension, diabetes, and dyslipidemia [2]. The prevalence of overweight and obesity has increased substantially in the past few decades [3,4] and has been responsible for 10% to 40% of all CVD deaths [5].

Body mass index (BMI) is commonly used to define obesity. However, BMI is not able to differentiate lean from fat mass [6–9]. Thus, recommendations have been made to use other measures of adiposity such as waist circumference (WC), which has shown to be a good predictor of abdominal fat and cardiovascular risk [10,11]. Regarding abdominal fat, subcutaneous and visceral fat would increase the risk for CVD, and visceral fat would be a better risk predictor [12]. Nakamura et al. reported that visceral fat (measured by computed tomography [CT]) was strongly associated with CVD among men with normal BMI (mean 23.8 kg/m^2) [13]. Fox et al. analyzed data from the Framingham Study and observed that the volume of visceral fat was more highly correlated with the risk for hypertension, impaired fasting glucose, and dyslipidemia than subcutaneous fat [14].

Atherosclerosis would be the main mechanism linking obesity to CVD [15,16]. As part of the atherosclerotic process, there is an increase in arterial stiffness, which has been associated with an increase in pulse wave velocity (PWV) [17–21]. Therefore, PWV has been used to measure arterial stiffening and it has been considered a strong predictor of CVD [22–27].

Regarding the association between PWV and adiposity, Czernichow et al. [28] observed that WC, but not BMI, was associated with PWV. Another study found that BMI ($r = 0.24$; $P = 0.05$) and WC ($r = 0.30$; $P = 0.01$) were positively correlated with PWV [29].

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Wildman et al. also reported a positive correlation between body composition measures (BMI, WC, waist-to-hip ratio [WHR]) and PWV, independent of age [30]. Furthermore, Brunner et al. [31] showed that progression of PWV was higher among obese individuals independently of the measure of body composition used (BMI, WC, WHR, and body fat percentage measured by body impedance). Conversely, we are not aware of any study assessing which body composition measure is more strongly associated with PWV. Moreover, most of the previously published studies were carried out with specific populations, such as the elderly; obese adults, children, and adolescents; patients with diabetes; patients with chronic kidney disease; and postmenopausal women [32–36]. To fill this gap in the literature, the present study aimed at assessing the association of several body composition measures with PWV among healthy young adults who were prospectively followed since birth.

Methods

In 1982, maternity hospitals located in Pelotas, a southern Brazilian city, were visited on a daily basis. Live-born infants whose family lived in the urban area of the city were examined and their mothers interviewed (N = 5914). The infants were followed up several times. Further details on the methods of the 1982 Pelotas Birth Cohort Study have been published elsewhere [37]. From 2012 to 2013, when the individuals were a mean age of 30.2 y, we attempted to locate all of them using multiples strategies. In all, 3701 individuals were interviewed and examined in the research clinic [38].

In the 2012 to 2013 visit, PWV was assessed in 1576 participants (42.6% of the interviewed individuals) using the Sphygmocor system (Atcor Medical, Version 9.0, Sydney, Australia). This non-invasive device measures the PWV with a tonometric transducer. A trained technician performed all measurements, after a 5-min rest, with the participant in the supine position in a quiet environment with controlled temperature (22°C–24°C). The tonometer was lightly pressed on the participant's skin after palpation of the right carotid and femoral pulses with simultaneous recording of the electrocardiogram. The average of two measurements was used.

PWV was estimated from measurements of pulse transit time and distance traveled by the pulse wave. Pulse transit time was assessed using the foot-to-foot method, and wave "feet" were identified by the software using intersecting tangent algorithms. The distance traveled by the pulse wave was measured using a flexible tape as the distance from suprasternal notch to the femoral site of pulse wave recording and the distance from carotid site of pulse wave recording and the suprasternal notch. This information was entered in the computer and PWV was estimated by the Sphygmocor software [39].

Physical activity was evaluated using the International Physical Activity Questionnaire (IPAQ), which was validated in Brazil in 2001 and is widely used in several countries [40]. Individuals who performed physical activity at least 150 min/wk were considered active.

Blood pressure was measured twice in the sitting position using a digital sphygmomanometer Omron model HEM-705CPINT (Omron, Beijing, China) on the left arm. The measurements were made in this way owing to logistics reasons because our purpose was not hypertension diagnosis. The mean of the two readings was used.

Each type of anthropometric and body composition measurement was performed by a single technician, previously trained in the pilot study.

Weight was measured to the nearest 0.1 kg using a calibrated electronic scale with a maximum capacity of 150 kg (TANITA BC-418 MA; Tanita, Tokyo, Japan) and height was measured to the nearest 0.1 cm with a portable stadiometer (SECA 240; Seca, Birmingham, UK). BMI was calculated by dividing the weight in kg by the square of height in meters. WC, fat mass, and abdominal fat thickness also were assessed. WC was measured using a flexible tape (Cescorf, Porto Alegre, Brazil) with an accuracy of 0.1 cm at the narrowest part of the trunk and the average of two measures was used. Fat mass and abdominal adipose tissue thickness were evaluated through plethysmography and ultrasound, respectively. The Bod Pod Gold Standard (Body Composition Tracking System) was used to estimate the percentage of fat mass [41]. Furthermore, a 3.5-MHz convex probe interfaced to a Toshiba Xario ultrasound machine (Toshiba Medical Systems Corp., Tokyo, Japan) was used to measure, in centimeters, visceral adipose tissue thickness (VATT), abdominal total subcutaneous adipose tissue thickness (ATSATT), abdominal superficial subcutaneous adipose tissue thickness (ASSATT), and abdominal deep subcutaneous adipose tissue thickness (ADSATT).

VATT is the distance in the sagittal plane of the peritoneum to the lumbar spine [42]. Subcutaneous adipose tissue thickness, in the transverse plane, is the distance between the skin and the linea alba [43]. Abdominal superficial subcutaneous adipose tissue thickness is separated from abdominal deep subcutaneous adipose tissue thickness by a deep fascial plane of fibroelastic connective tissue, which is evidenced in the ultrasound image. The measurements were made at the intersection between the xyphoid line and the WC.

Data analyses were performed using Stata 12 statistical package (StataCorp. College Station, TX, USA). Spearman's correlation was used to assess the correlation between body fat measures (BMI, WC, fat mass, and abdominal adipose tissue thickness) and PWV. Multiple linear regression was used to estimate crude and adjusted regression coefficients for the association between body fat measures and PWV. Estimates of each body fat measures (BMI, WC, fat mass, and abdominal adipose tissue thickness) were adjusted for sex, race, maternal schooling, family income, maternal smoking during pregnancy, and birth weight. Body fat measures were converted to *z*-score, using mean and standard deviation, to allow comparability because the measurements were obtained in different measurement scales.

This study was approved by the Research Ethics Committee of the Faculty of Medicine, Federal University of Pelotas, affiliated with the National Council on Ethics in Research of the Ministry of Health. All participants signed an informed consent.

Results

In the 2012 to 2013 follow-up, 3701 individuals were evaluated. When added to the 325 who were known to have died, this represented a follow-up rate of 68.1%. PWV was assessed in 1576 participants (42.6% of the interviewed individuals).

Among the individuals included in the present analysis, 75.3% were white, 25% were smokers, and 23.7% were obese (Table 1). Only 30% performed ≥150 min/wk of physical activity.

The distribution of body composition variables by sex is shown in Table 2. Although the mean BMI was similar between men and women, the percentage of women's fat mass was higher than that of men (40.8% versus 28.9%; $P < 0.0001$). Regarding adipose tissue, men presented higher visceral fat than women (6.87 versus 4.84 cm; $P < 0.0001$).

Table 3 shows the correlation matrix of PWV with body composition variables. PWV was positively correlated with all body composition measurements evaluated, and the correlation coefficient was higher for BMI, WC, VATT, and fat mass. Among the adipose thickness measured by ultrasound, VATT showed the highest correlation with PWV.

In the linear regression analysis, all body composition variables were associated with PWV, even after adjusting for potential confounders (sex, race, birth weight, family income, family education, maternal smoking during pregnancy). The highest regression coefficients were

Table 1
Characteristics of the studied population

Variables	n (%)
Sex	
Male	804 (51.1)
Female	770 (48.9)
Race	
White	1185 (75.3)
Non-white	389 (24.7)
Achieved schooling (y)	
0–4	104 (6.7)
5–8	309 (19.9)
9–11	458 (29.4)
≥12	684 (44)
Smoking at 30 y	
Yes	391 (25)
No	1167 (75)
Body mass index (kg/m^2)	
<25	663 (42.2)
25–29	536 (34.1)
≥30	373 (23.7)
Physical activity (min/wk)	
≥150	459 (29.6)
<150	1093 (70.4)

Table 2
Distribution of body composition variables by sex

Variables	Mean ± SD		n	
	Male	Female	Male	Female
BMI (kg/m^2)	27.06 ± 5.13	26.82 ± 5.97	803	764
WC (cm)	89.72 ± 11.99	80.99 ± 12.17	803	770
Fat mass (%)	28.95 ± 10.43	40.81 ± 8.92	762	756
VATT (cm)	6.87 ± 1.99	4.84 ± 1.67	790	758
ATSATT (cm)	1.93 ± 1.0	2.56 ± 1.13	797	760
ASSATT (cm)	0.66 ± 0.34	1.03 ± 0.51	797	760
ADSATT (cm)	1.27 ± 0.76	1.53 ± 0.80	797	760

ADSATT, abdominal deep subcutaneous adipose tissue thickness; ASSATT, abdominal superficial subcutaneous adipose tissue thickness; ATSATT, abdominal total subcutaneous adipose tissue thickness; BMI, body mass index; VATT, visceral adipose tissue thickness; WC, waist circumference

observed for BMI (β = 0.30; 95% confidence interval [CI], 0.25–0.35), VATT (β = 0.30; 95% CI, 0.24–0.35), and fat mass (β = 0.30; 95% CI, 0.24–0.35; Table 4).

Discussion

In a cohort that was prospectively followed since birth in a southern Brazilian city, PWV was positively correlated with body composition measures at 30 y of age. BMI, VATT, and fat mass were the strongest predictors. Concerning the limitations of the study, PWV was not assessed in all individuals who were evaluated at the age of 30 years, but the probability of PWV examination was independent of socioeconomic status, breastfeeding duration, maternal smoking during pregnancy, and physical activity at 30 y. Therefore, selection bias is unlikely and so the studied individuals can be considered representative of all the cohort participants.

BMI and WC are the most widely used measures of obesity. Both are easy to perform, low cost, and reproducible, but they are unable to disentangle fat from fat-free mass and are not the best predictors of cardiovascular risk [9]. Bod Pod is able to measure fat mass and lean mass in percentage [41], but its high cost and the need for trained personnel make it difficult to use on a large scale. CT and magnetic resonance imaging (MRI) are the gold standard for quantification of abdominal adiposity [44,45], but these methods are expensive and not radiation free (CT), precluding the assessment in large populations. One of the strengths of the present study was that we were able to perform various body composition measures, such as fat mass, using the Bod Pod, and abdominal adipose tissue thicknesses, by ultrasound. Abdominal ultrasound estimates visceral adipose tissue more accurately than BMI or WC [46,47] and is safe, accurate, and reproducible [42,48–50]. Armellini et al. and Grandmark et al. found a good correlation, 0.67 and 0.79, respectively, between ultrasonography VATT and CT intra-abdominal adipose tissue area [51,52]. In the present study, WC showed a slightly better correlation

Table 4
Associations between PWV and body composition at 30 y obtained from multiple linear regression adjusted for confounding factors

Body composition variables	β (in m/s)	R^2	Adjusted β*
Body mass index *z*-score	0.30 (0.25–0.36)	7.82	0.30 (0.25–0.35)
Waist circumference *z*-score	0.29 (0.24–0.34)	7.28	0.29 (0.24–0.34)
Fat mass *z*-score	0.30 (0.25–0.35)	7.48	0.30 (0.24–0.35)
ATSATT *z*-score	0.24 (0.19–0.30)	5.01	0.24 (0.19–0.30)
ASSATT *z*-score	0.20 (0.14–0.25)	3.01	0.19 (0.14–0.25)
ADSATT *z*-score	0.23 (0.18–0.28)	4.51	0.23 (0.18–0.28)
VATT *z*-score	0.30 (0.25–0.35)	7.31	0.30 (0.24–0.35)

ADSATT, abdominal deep subcutaneous adipose tissue thickness; ASSATT, abdominal superficial subcutaneous adipose tissue thickness; ATSATT, abdominal total subcutaneous adipose tissue thickness; CI, confidence interval; PWV, pulse wave velocity; VATT, visceral adipose tissue thickness
*Adjusted for sex, race, birth weight, family income, family education, maternal smoking during pregnancy.

with VATT (r = 0.7070) than BMI (r = 0.6707), demonstrating that for clinical purposes, WC should be preferred for this estimation.

Visceral adipose tissue (VAT) has been associated with hypertension, insulin resistance, and diabetes [14], which increase the risk for atherosclerosis. Sironi et al [53] found that VAT, measured by magnetic resonance imaging, was 60% larger in hypertensive than in normotensive individuals ($P < 0.003$). Kobayashi et al. found that VAT, measured by CT, was positively correlated with the severity of coronary lesions (r = 0.43; $P < 0.01$) and insulin resistance (r = 0.49; $P < 0.01$) [54]. Furthermore, Ren et al. [55] found an association between VAT (measured by CT) and carotid intima-media thickness, which is an indicator of subclinical atherosclerosis [56]. Our finding of a positive correlation between VAT and PWV is in agreement with these studies because PWV evaluates arterial stiffness that is closely related to the atherosclerotic process [17–21].

This study could compare the association of PWV with adiposity markers from more sophisticated methods, such as ultrasound or Bod Pod, and simple anthropometric measurements, such as BMI and WC. We found that there is a similar correlation among these methods and PWV. As previously mentioned, few studies have compared the association of different body composition measures of adiposity with PWV. Fantin et al. [57] observed that the correlation with PWV was slightly higher for central fat (r = 0.33; $P < 0.01$) than for BMI or WC (r = 0.28 r = 0.27; $P < 0.01$), whereas Brunner et al. [31] observed that WC presented the strongest association with PWV (BMI: r = 0.14; 95% CI, 0.05–0.24; WC: r = 0.18; 95% CI, 0.08–0.27; WHR: r = 0.16; 95% CI, 0.07–0.24; fat mass percent: r = 0.14; 95% CI, 0.05–0.23). Wildman et al. [30] observed that WC showed the highest correlation coefficient with PWV among young individuals (BMI: r = 0.21, P = 0.004, WC: r = 0.24, P = 0.001; WHR: r = 0.19, P = 0.01), whereas among older individuals, the correlation coefficient for BMI and WC were similar (BMI: r = 0.26, P = 0.001; WC: r = 0.27, P = 0.001; WHR: r = 0.23, P = 0.002).

Table 3
Correlation matrix for PWV and body composition variables

Variables	PWV	BMI	WC	Fat mass	ATSATT	ASSATT	ADSATT	VATT
PWV	1.0000							
BMI	0.2805	1.0000						
WC	0.2698	0.9316	1.0000					
Fat mass	0.2749	0.9494	0.9156	1.0000				
ATSATT	0.2226	0.7558	0.7733	0.8031	1.0000			
ASSATT	0.1726	0.6255	0.6620	0.6601	0.7857	1.0000		
ADSATT	0.2112	0.6941	0.6969	0.7401	0.9409	0.5337	1.0000	
VATT	0.2697	0.6707	0.7070	0.6630	0.3811	0.3350	0.3369	1.0000

ADSATT, abdominal deep subcutaneous adipose tissue thickness; ASSATT, abdominal superficial subcutaneous adipose tissue thickness; ATSATT, abdominal total subcutaneous adipose tissue thickness; BMI, body mass index; PWV, pulse wave velocity; VATT, visceral adipose tissue thickness; WC, waist circumference

On the other hand, other studies have not reported an association between BMI and PWV, which is in contrast to ours results where BMI showed the strongest correlation ($r = 0.2805$). Bouchi et al. [58], in a cross-sectional study with patients with diabetes and normal BMI, observed that visceral fat (measured by bioelectrical impedance) was positively associated with PWV, showing that even in non-obese individuals with diabetes, increased visceral fat seems to be associated with increased arterial stiffness. Sutton-Tyrrell et al. [59] evaluated older individuals (70–79 y of age) and observed that visceral adipose tissue, measured by CT, was the strongest body fat measure associated with PWV, regardless of weight.

Conclusions

In the present study, BMI was as good as VAT and fat mass in predicting PWV. Another interesting finding is that WC had a better correlation with VAT than BMI. Despite the evidence suggesting that VAT seems to be the body fat measure that has a better association with increased cardiovascular risk, its measurement requires personnel and sophisticated equipment, whereas BMI and WC can be done easily in primary care to identify people at increased cardiovascular risk.

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