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Examining the Relationship Between Pulse Wave Characteristics and Components of Body Composition Among College Aged Vapers and Non-vapers

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Abstract

Background The purpose of this investigation was to examine the relationship between pulse wave characteristics (i.e., pulse wave velocity and pulse wave analysis) and body composition (i.e., body fat percentage [BF%], visceral fat percentage [VF%], and bone mineral density [BMD]) among college-aged vapers and non-vapers. Seventy-four females were classified as a vaper or non-vaper and completed a dual energy x-ray absorptiometry scan and arterial stiffness assessment. All body composition variables were collapsed into tertiles (i.e., low, moderate and high) and separate two-way, 2 (Group [vaper, non-vaper]) × 3 (Rank [low, moderate, high]) ANOVAs were performed.

Results There were significant ($p = 0.005–0.031$) interactions for VF%, whereby greater brachial diastolic blood pressure (BDBP), central diastolic blood pressure (CDBP), and central mean arterial pressure (CMAP) was observed among vapers classified has $High_{VF\%}$ (77.9 ± 8.9 mmHg, 78.5 ± 9.0 mmHg, 93.5 ± 9.4 mmHg, respectively) compared to $Moderate_{VF\%}$ (66.5 ± 9.3 mmHg, 67.5 ± 9.4 mmHg, 81.5 ± 8.9 mmHg, respectively). For BMD, there were significant ($p = 0.010–0.040$) main effects of Rank, whereby, BDBP and CDBP were greater among Low_{BMD} (75.1 ± 7.2 mmHg and 76.4 ± 7.2 mmHg, respectively) compared to $Moderate_{BMD}$ (71.3 ± 6.6 mmHg and 72.0 ± 6.6 mmHg, respectively).

Conclusion Greater VF%, along with vaping status induced adverse values for pulse wave characteristics, while BF% and BMD did not have a relationship with vaping status. Additionally, there were no differences among non-vapers with high VF%, suggesting vaping status further impacts pulse wave characteristics.

Keywords Arterial stiffness, Body composition, Electronic cigarette

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1 Background

Electronic cigarettes (i.e., vape devices) are commonly used amongst college students [1]. These devices are typically powered by a lithium-ion battery which heat liquids to different temperatures that contain varying levels of nicotine, flavourings, and propellants [2, 3]. Across all users, young adults gravitate towards vaping for a variety of reasons. These reasons include, but are not limited to peer pressure, weight loss, energy, and focus [4, 5]. Although there is less known regarding the chronic impacts associated with vaping due to its novelty, previous investigations examining the acute effects have shown the detrimental consequences to the vasculature [6, 7].

Additives within nicotine (i.e., propylene glycol/glycerol and nicotine) have been shown to impact pulmonary function, such that acute vaping of propylene glycol/glycerol aerosol at high wattage with or without nicotine can induce airway epithelial injury and sustained levels of low transcutaneous oxygen tension [8]. The effects of propylene glycol/glycerol on the vasculature, however, is not clear. For example, acute vaping of propylene glycol/glycerol with nicotine has been shown to lead to increases arterial stiffness (AS) (measured via pulse wave velocity [PWV]) (pre: 4.9 ± 0.1 m/s^{-1} versus post: 5.3 ± 0.1 m/s^{-1}) relative to vaping without nicotine (pre: 5.1 ± 0.1 m/s^{-1} versus post: 5.3 ± 0.1 m/s^{-1}) [9]. Further, vaping liquid that contains propylene glycol/glycerol has been shown to cause endothelial cell dysfunction [10] and lead to increases brachial systolic blood pressure (BSBP) (pre: 120 ± 5 mmHg versus post: 126 ± 5 mmHg), brachial diastolic blood pressure (BDBP) (pre: 66 ± 3 mmHg versus post: 72 ± 2 mmHg), and central mean arterial pressure (CMAP) (pre: 86 ± 3 mmHg versus post: 92 ± 3 mmHg) in young adults [11]. Additionally, following an acute session of vaping, there were significant increases in carotid-femoral PWV (pre: 8.2 ± 0.26 m/s^{-1} versus post: 8.94 ± 0.33 m/s^{-1}) and augmentation index at 75 beats per minute (AIx 75) (pre: 7.97 ± 2.97% versus post: 13.55 ± 3.24%) [12]. Thus, vaping seems to be detrimental to the vasculature by augmenting various pulse wave characteristics (i.e., greater BSBP, BDBP, CMAP, PWV, and AIx 75) [9–12].

Along with vaping, there are other factors that affect AS which include modifiable (e.g., body fat) and non-modifiable (e.g., age) risk factors. Of the modifiable risk factors, maintaining a healthy body composition is critical as high body fat levels have been shown to increase AS [13–18]. However, much of this literature focuses on older, obese, and clinical populations which therefore limits its application to other populations, such as young adults. Alternatively, there have been investigations looking at the relationship between vaping and different levels of body fat in younger populations. For example, obese subjects had a greater odds ratio (OR) of using cigarettes/vape devices compared to other substances (OR = 4.4) and alcohol (OR = 1.94) [19]. Additionally, young adults who reported vaping tended to exhibit unhealthy habits, such as smoking and alcohol consumption, whose combination may contribute to overall higher levels of body fat accumulation [20].

Although there is evidence that both vaping and poor body composition independently affect pulse wave characteristics, it is unknown how the relationship of different body composition variables affects pulse wave characteristics in those who vape. Additionally, previous investigations have examined these relationships separately [9–18], thus limiting our understanding of the potential impact other body composition variables (e.g., visceral fat percentage [VF%] and bone mineral density [BMD]) might have on pulse wave characteristics in young adults. The purpose of this investigation was to examine the relationship between pulse wave characteristics and body composition characteristics among college-aged vapers and non-vapers. Based off previous investigations [9–12, 19], we hypothesized that vapers would demonstrate worse body composition and pulse wave characteristics than non-vapers.

2 Methods

2.1 Study Design

This cross-sectional study involved one testing visit at the Human Performance Laboratory. Anthropometrics (i.e., height and weight) and a dual energy x-ray absorptiometry scan (DEXA, Hologic Discovery DXA Bone Densitometry System, Marlborough, MA) were done before the AS measurement. Once completed, subjects were instructed to lie down for five minutes to allow blood pressure to normalize. Measurements were taken on the right side of the body.

2.2 Participants

Seventy-four (19.45 ± 2 years; 164.71 ± 7.32 cm; 60.89 ± 9.25 kg) college-aged females participated in this investigation. Inclusion criteria consisted of students at the University of Tampa between 18 and 35 years old. Exclusion criteria consisted of pregnancy, participating in a current clinical study, any chronic health conditions, and/or any present signs and symptoms of COVID-19. The questionnaire was sent via email to determine vaping status which allowed for classification into the vaper or non-vaper groups. Participants who indicated having vaped within the last 30 days were classified as a vaper. All other participants were classified as non-vapers. A written informed consent was obtained from all the participants prior to the study intervention.

This investigation was approved by the University's Institutional Review Board and is in accordance with the Declaration of Helsinki [21].

2.3 Measurements

2.3.1 Dual Energy X-Ray Absorptiometry Scan

The DEXA scan (Hologic Discovery DXA Bone Densitometry System, Marlborough, MA) uses a low level of radiation (X-Ray) to measure, fat mass (i.e., body fat percentage [BF%]), VF%, BMD. Participants were asked to refrain from food, water, alcohol, and nicotine at least twelve hours prior to the scan. Height was measured to the nearest 0.1 cm with a stadiometer (Detecto 438, Webb City, MO, USA), and body weight was measured to the nearest 0.1 kg on a weight scale (Detecto 438, Webb City, MO, USA). Each participant removed any metallic items on the body prior to the scan and were instructed to lie supine for measurements with their arms by their side and their feet pigeon toed together. BF%, VF% and BMD were split into tertiles and later used for analyses.

2.3.2 Pulse Wave Analysis

After resting for five minutes in a supine position, an automated brachial blood pressure cuff was placed on the right arm using the SphygmoCor XCEL (SphygmoCor XCEL, AtCor Medical, Sydney, Australia). This device provides measurements of pulse wave reflection and pressure waveforms through a validated general transfer function [22]. After measuring BSBP and BDBP, the device deflated and then inflated once more to calculate other variables. These include resting heart rate (RHR), central systolic and diastolic blood pressure (CSBP and CDBP), augmentation pressure (AP), pulse pressure (PP), CMAP, AIx, and AIx 75. Once complete, the BSBP and BDBP obtained were inputted into the system for PWV measurements.

2.3.3 Arterial Stiffness

Carotid-femoral PWV measurements were performed to determine AS using the SphygmoCor XCEL device (SphygmoCor XCEL, AtCor Medical, Sydney, Australia). All measurements were performed on the right side of the body where a cuff was positioned around the patient's upper thigh to capture femoral pulse waves while a tonometer was placed on the carotid artery to capture carotid pulse waves. Prior to the assessment, distances on the body were measured and inputted into the software to allow for the determination of PWV via the subtraction method. These measurements included the distance from the carotid artery to the top of the sternal notch, the sternal notch to the top of the thigh cuff, and the femoral artery to the top of the thigh cuff. Each participants carotid artery was palpated and marked to ensure the tonometer was placed in the correct position. After these measurements, the tonometer was placed on the carotid artery and PWV was recorded. Measurement of PWV was taken until the quality control check was established to ensure an accurate reading (i.e., less than 10% error). If the quality control was not checked, another measurement was immediately taken.

2.4 Statistical Analysis

Tests for normality and homogeneity of variance were performed using Shapiro–Wilk and Levene's test for homogeneity of variance, respectively. If a variable violated normality or variance, a Mann–Whitney U or Welch's *t*-test was used, respectively. Multiple Bonferroni-corrected independent samples *t*-tests were conducted to determine potential mean differences between groups for all the variables. Separate two-way, 2 (Group [vaper, non-vaper])×3 (Rank [low, moderate, high]) ANOVAs were conducted to determine potential mean differences in pulse wave characteristics (i.e., PWV and PWA [RHR, BSBP, BDBP, CSBP, CDBP, PP, CMAP, AP, AIx, and AIx 75]) among vapers and non-vapers, factored by BF%, VF%, and BMD. All significant interactions were decomposed when necessary and Bonferroni-corrected dependent samples *t*-tests were used for any main effects. A Greenhouse-Geiser correction was applied when Mauchly's test of sphericity was not met. Partial eta-squared effect sizes (η_p^2) and Hedges *g* effect sizes were computed for each ANOVA and Bonferroni-corrected dependent samples *t*-test, respectively. All statistical analyses were performed with Jamovi statistical software V 2.3.15 (Sydney, AU) and all graphs were made with GraphPad Prism V 9.4.1 (Boston, MA).

3 Results

3.1 Demographics

Table 1 includes the demographics of the participants. Out of the participants, 23 were classified as a vaper and 51 as a non-vaper. Overall, none of the variables were significant ($p > 0.05$), indicating no differences in baseline characteristics between vapers and non-vapers.

3.2 Body Fat Percentage

There were no significant ($p = 0.078$–0.852; $\eta_p^2 = 0.005$–0.073) interactions or main effects for Group ($p = 0.179$–0.919; $\eta_p^2 = 0.003$–0.027) or Rank ($p = 0.078$–0.604; $\eta_p^2 = 0.015$–0.056) for BSBP, RHR, CSBP, PP, AP, AIx, AIx 75, or PWV. There were, however, significant interactions for BDBP ($p = 0.024$; $\eta_p^2 = 0.105$), CDBP ($p = 0.041$; $\eta_p^2 = 0.091$), and CMAP ($p = 0.037$; $\eta_p^2 = 0.093$) (Figs. 1a-1c). Follow-up simple main effects of Rank within Group indicated no significant differences ($p > 0.05$) for BDBP,

Table 1 Demographics among vapers and non-vapers

Variables	Vaper Mean ± SD	Non-Vaper Mean ± SD	*p*-value
Age (years)	19.4 ± 1.4	19.5 ± 2.2	0.876
Height (cm)	165.0 ± 9.1	165.0 ± 6.5	0.958
Body weight (kg)	59.6 ± 9.2	61.5 ± 9.3	0.405
BF%	25.9 ± 4.5	27.8 ± 6.2	0.179
VF (g)	177.0 ± 74.0	187.0 ± 119	0.720
BMD (g/cm^2)	1.1 ± 0.1	1.1 ± 0.1	0.136
RHR (bpm)	65.7 ± 11.4	68.8 ± 9.9	0.242
BSBP (mmHg)	122.0 ± 8.4	123 ± 8.3	0.659
BDBP (mmHg)	73.0 ± 9.4	73.6 ± 5.5	0.761
CSBP (mmHg)	107.0 ± 8.4	108.0 ± 6.9	0.624
CDBP (mmHg)	74.0 ± 9.4	74.7 ± 5.6	0.667
PP (mmHg)	33.5 ± 4.9	33.7 ± 5.7	0.908
CMAP (mmHg)	88.6 ± 9.8	89.7 ± 6.3	0.555
AP (mmHg)	5.3 ± 4.1	5.7 ± 3.7	0.634
AIx %	14.5 ± 10.0	16.1 ± 9.6	0.523
AIx 75%	11.4 ± 10.6	13.1 ± 10.8	0.549
PWV (m/s)	5.4 ± 0.8	5.4 ± 0.7	0.975

Values are mean ± standard deviation

BMI body mass index, *BF%* body fat percentage, *VF* visceral fat in grams, *BMD* bone mineral density, *RHR* resting heart rate, *bpm* beats per minute, *BSBP* brachial systolic blood pressure, *mmHg* millimetres of mercury, *BDBP* brachial diastolic blood pressure, *CSBP* central systolic blood pressure, *CDBP* central diastolic blood pressure, *PP* pulse pressure, *CMAP* central mean arterial pressure, *AP* augmentation pressure, *AIx* augmentation index, *AIx 75* augmentation index normalized to 75 beats per minute, *PWV* pulse wave velocity, *m/s* meters per second

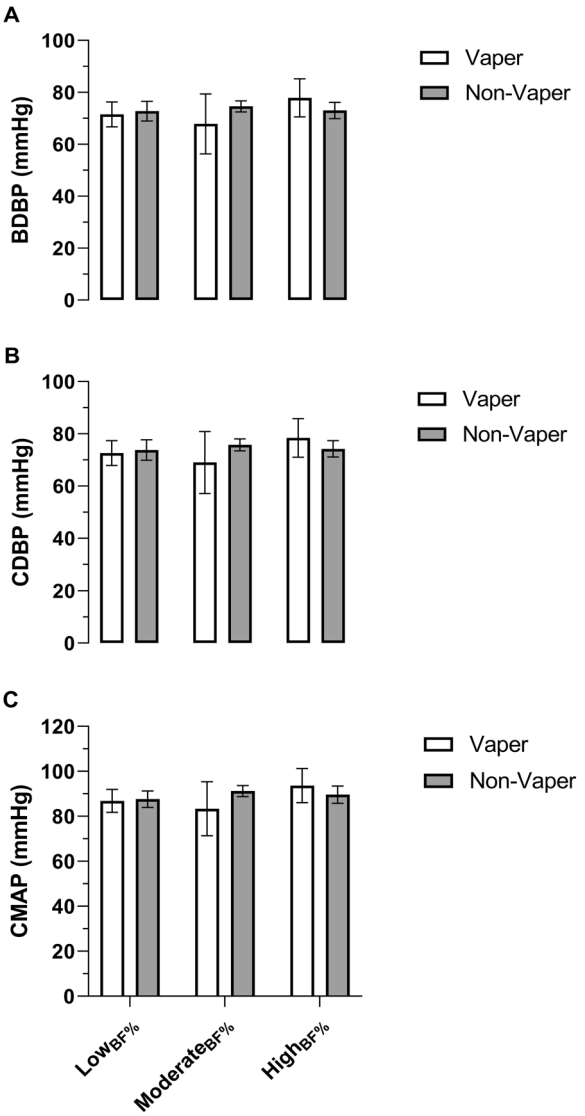

Fig. 1 **a**-**c** Displays the mean ± 95% confidence interval (95% CI) for brachial diastolic blood pressure (BDBP; **a**), central diastolic blood pressure (CDBP; **b**), and central mean arterial pressure (CMAP; 1c) among vapers and non-vapers stratified by low body fat percentage ($Low_{BF\%}$), moderate body fat percentage ($Moderate_{BF\%}$), and high body fat percentage ($High_{BF\%}$)

CDBP, or CMAP. Additionally, follow-up simple main effects of Group within Rank indicated no significant differences ($p > 0.05$) for BDBP, CDBP, or CMAP.

3.3 Visceral Fat Percentage

There were no significant ($p = 0.084$–0.719; $\eta_p^2 = 0.010$–0.070) interactions or main effects for Group ($p = 0.273$–0.994; $\eta_p^2 = 0.007$–0.018) or Rank ($p = 0.058$–0.880; $\eta_p^2 = 0.051$–0.082) for BSBP, CSBP, PP, AP, AIx, AIx 75, or PWV. There were, however, significant interactions for BDBP ($p = 0.028$; $\eta_p^2 = 0.101$), HR ($p = 0.005$; $\eta_p^2 = 0.149$), CDBP ($p = 0.031$; $\eta_p^2 = 0.098$), and CMAP ($p = 0.017$; $\eta_p^2 = 0.114$) (Fig. 2a–d). Follow-up simple main effects of Rank within Group indicated greater BDBP among vapers classified has $High_{VF\%}$ (77.9 ± 8.9 mmHg) compared to $Moderate_{VF\%}$ (66.5 ± 9.3 mmHg) ($p = 0.007$; $g = 1.19$). For RHR, it was greater among vapers classified as $Low_{VF\%}$ (76.0 ± 7.5 bpm) compared to $Moderate_{VF\%}$ (56.6 ± 8.3 bpm) ($p = 0.014$; $g = 2.28$). For CDBP, it was greater among vapers classified as $High_{VF\%}$ (78.5 ± 9.0 mmHg) compared to $Moderate_{VF\%}$ (67.5 ± 9.4 mmHg) ($p = 0.013$; $g = 1.14$). For CMAP, it was greater among vapers classified as $High_{VF\%}$ (93.5 ± 9.4 mmHg) compared to $Moderate_{VF\%}$ (81.5 ± 8.9 mmHg) ($p = 0.011$; $g = 1.25$). Follow-up simple main effects of Group within Rank indicated greater HR among $Moderate_{VF\%}$ for non-vapers (70.2 ± 7.8 bpm) compared to vapers (56.6 ± 8.3 bpm) ($p = 0.026$; $g = 1.64$). There were no other significant ($p > 0.05$) simple main effects.

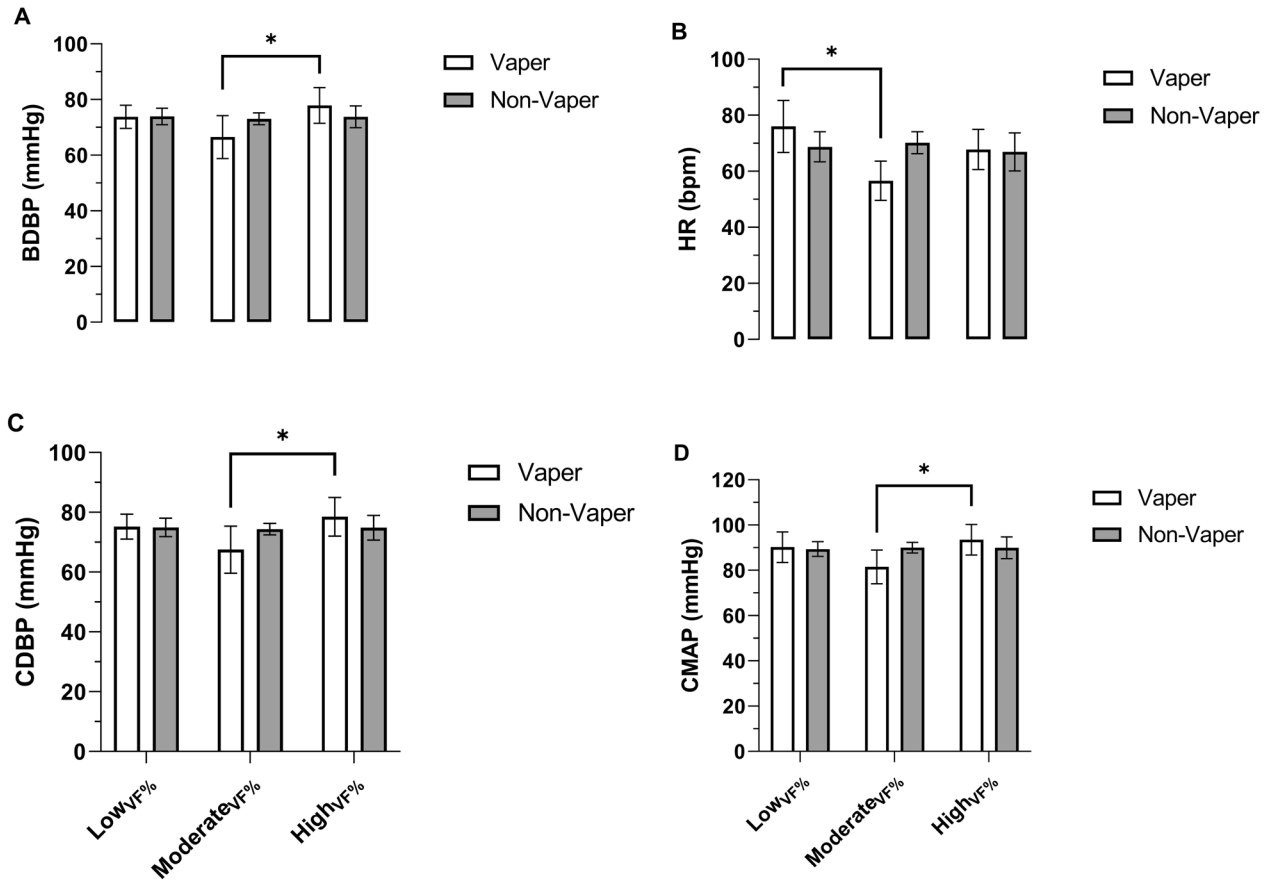

Fig. 2 **a**–**d** Displays the mean ± 95% confidence interval (95% CI) for brachial diastolic blood pressure (BDBP; **a**), heart rate (HR; **b**), central diastolic blood pressure (CDBP; **c**), and central mean arterial pressure (CMAP; **d**) among vapers and non-vapers stratified by low visceral fat percentage ($Low_{VF\%}$), moderate visceral fat percentage ($Moderate_{VF\%}$), and high visceral fat percentage ($High_{VF\%}$). *denotes $p < 0.05$

3.4 Bone Mineral Density

There were no significant ($p = 0.082$–0.983; $\eta_p^2 = 0.017$–0.071) interactions or main effects for Group ($p = 0.440$–0.922; $\eta_p^2 = 0.002$–0.009) or Rank ($p = 0.077$–0.895; $\eta_p^2 = 0.003$–0.074) for BSBP, RHR, CSBP, CMAP, AP, AIx, AIx 75, or PWV. There were, however, significant main effects of Rank for BDBP ($p = 0.040$; $\eta_p^2 = 0.091$), CDBP ($p = 0.015$; $\eta_p^2 = 0.117$), and PP ($p = 0.010$; $\eta_p^2 = 0.129$) (Fig. 3a–c). Follow up Bonferroni-corrected dependent samples *t*-tests collapsed across Group indicated greater BDBP among those classified as Low_{BMD} (75.1 ± 7.2 mmHg) compared to $Moderate_{BMD}$ (71.3 ± 6.6 mmHg) ($p = 0.047$; $g = 0.54$). For CDBP, it was greater among those classified as Low_{BMD} (76.4 ± 7.2 mmHg) compared to $Moderate_{BMD}$ (72.0 ± 6.6 mmHg) ($p = 0.019$; $g = 0.63$). For PP, it was lower among those classified as Low_{BMD} (31.8 ± 5.9 mmHg) compared to $Moderate_{BMD}$ (35.9 ± 4.8 mmHg) ($p = 0.012$; $g = 0.75$).

4 Discussion

The main findings of the present investigation indicated greater BDBP, CDBP, and CMAP among vapers classified as $High_{VF\%}$ compared to $Moderate_{VF\%}$ and greater RHR among vapers classified as $Low_{VF\%}$ compared to $Moderate_{VF\%}$. Between groups, greater RHR was observed among $Moderate_{VF\%}$ for non-vapers than vapers. Additionally, BDBP and CDBP were greater among Low_{BMD} compared to $Moderate_{BMD}$, whereas PP was lower among Low_{BMD} compared to $Moderate_{BMD}$. There were no differences in vaping status or body composition components for BSBP, CSBP, AP, AIx, AIx 75, or PWV. Collectively, the present findings suggest that VF% and vaping status adversely impacts certain pulse wave characteristics, while BMD does in the absence of vaping status.

Previous investigations have separately examined the relationship between body composition and pulse wave characteristics [13–18, 23–32], as well as vaping status

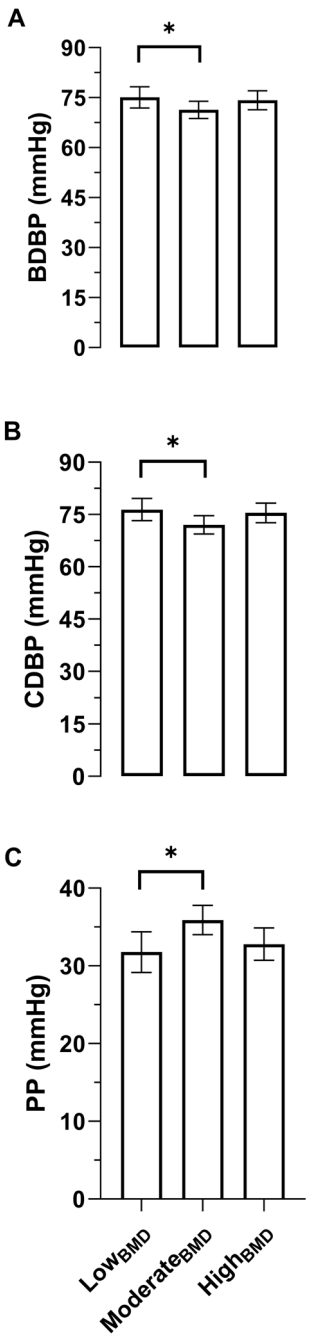

Fig. 3 **a**-**c** Displays the mean ± 95% confidence interval (95% CI) for brachial diastolic blood pressure (BDBP; **a**), central diastolic blood pressure (CDBP; **b**), and pulse pressure (PP; **c**) collapsed across Group for low bone mineral density (Low_{BMD}), moderate bone mineral density ($Moderate_{BMD}$), and high bone mineral density ($High_{BMD}$). *denotes $p < 0.05$

and pulse wave characteristics [6–8, 10–12, 33, 34]. Thus, to our knowledge, this is the first investigation examining the relationship between vaping status and body composition components and how it may affect pulse wave characteristics among college-aged females. The present findings showed no significant relationships for BF% and pulse wave characteristics among vapers and non-vapers. These findings are partially consistent with previous investigations [35, 36] which have examined the use of vaping and body weight management. Specifically, among adolescents and young adults, a common reason to begin vaping is that it could potentially aid in weight management [35, 36]. For example, females who vaped reported a greater positive expectancy (i.e., 1–7 scale ranging from strongly disagree to strongly agree) of weight control (4.11 ± 1.85 au) relative to males who vaped (3.93 ± 1.68 au) [35]. Contrarily, vaping use was reported to be higher in obese males (12% of the sample) than females (6% of the sample) who were intending to lose weight [36]. Collectively, among young males and females, a common reason for vaping is to control body weight. Thus, it is possible that participants classified as vapers in the current investigation may have been doing so to control body weight [5, 35, 36], possibly leading to the lack of differences for BF%. It is also possible that since there were no statistical differences in BF% between groups (Table 1), it made it difficult to detect differences in pulse wave characteristics among vapers and non-vapers when factored by BF%.

The present findings suggest that VF% had the most impact, whereby greater BDBP, CDBP, and CMAP were observed among vapers classified as $High_{VF\%}$ compared to $Moderate_{VF\%}$. Our findings are partially consistent with previous investigations [37–39] examining the relationship between VF and pulse wave characteristics among men and women. For example, among older women (≥ 40 years) there were greater BSBP's and BDBP's among those classified with high (123.6 ± 14.3 mmHg and 76.7 ± 8.7 mmHg, respectively) compared to low (118.6 ± 14.4 mmHg and 73.3 ± 9.1 mmHg, respectively) visceral adiposity index [37]. Additionally, among adult females (32.1 ± 15.2 years), there were significant correlations between visceral adiposity index and BSBP ($r = 0.823$) and BDBP ($r = 0.824$) [38]. Moreover, after controlling for age and sex, the change in visceral fat area was positively correlated ($r = 0.33$) with a 10-year follow-up of PP (pre to post measures after 10 years [39]. Thus, in conjunction with previous investigations [37–39], our findings indicated that $High_{VF\%}$ leads to increases in pulse wave characteristics (i.e., BDBP, CDBP, and CMAP), however, this relationship was only evident among vapers.

Visceral fat represents the amount of adipose tissue surrounding internal organs, whereby higher amounts have been associated with cardiac and/or metabolic issues [23]. Additionally, higher amounts of body fat (i.e., more VF) and vaping use independently have

been shown to raise blood pressure, [9, 24, 28, 34] thus blunting endothelium-dependent vasodilation and nitric oxide release [40]. Therefore, it is possible that in the present investigation, the combination of $High_{VF\%}$ and vaping status led to lower vasodilation, thus increasing BDBP, CDBP, and CMAP. Importantly, this effect was only observed among vapers. Therefore, vaping may lead to additional adverse alterations to the vasculature, such that BDBP, CDBP, and CMAP become elevated. Although BDBP and CDBP were elevated among vapers with $High_{VF\%}$, we did not observe elevations or other differences in pulse wave characteristics. This may be attributed to differences in peripheral vascular resistance or tone [41, 42], along with the lack of differences between groups for PWV, AIx, and/or PP [43–45]. Specifically, BDBP may be more affected by peripheral vascular resistance or tone as it reflects the pressure in the arteries while the heart is at rest. BSBP may be more affected by large artery stiffness and stroke volume as it reflects the pressure in the arteries while the heart is contracting. Thus, the simultaneous differences in both BDBP and CDBP, but lack of differences in BSBP and CSBP may potentially be attributed to greater peripheral vascular resistance, tone, and/or similar PWV, AIx, and PP values among vapers with $High_{VF\%}$.

For BMD, there were no differences in pulse wave characteristics between vapers and non-vapers. However, there were significant main effects of Rank for BDBP, CDBP, and PP. These findings are partially consistent with previous investigations [46, 47]. For example, among older men and women, there were significant relationships between BMD in the lumbar spine region and BSBP (95% confidence interval [CI] = 0.058–7.752) along with BMD in the femur neck region and BDBP (95% CI = − 0.766 to − 0.016) after adjustments for multiple variables (i.e., age, sex, BMI, etc.) [46]. Additionally, in elderly women, measurements of BMD across a two-year period collapsed into quartiles (i.e., stratified by BSBP) showed a significant relationship between BMD loss and BSBP increases from quartile 1 (BSBP of < 124 mmHg; BMD loss = 2.26 mg/cm^2) to quartile 4 (BSBP of ≥ 148 mmHg; BMD loss = 3.79 mg/cm^2) [47]. Together, a potential inverse relationship between BSBP/BDBP and BMD may exist, which agrees with the findings of the present investigation. There was, however, no impact of vaping on BMD. Vaping consists of numerous flavoring chemicals, nicotine, and propylene glycol, which systematically may impact highly vascularized tissues such as bone [48]. Although harmful, these effects may not have been detectable due to the current sample (i.e., young, healthy college-aged females) and/or not identifying the amount of flavoring chemicals, nicotine, and propylene glycol.

4.1 Limitations

In the present investigation, we collapsed our sample into different tertiles to examine the relationship between body composition components and pulse wave characteristics. Thus, these tertiles (i.e., low, moderate, and high) made our sample size smaller and may not have been equally split, potentially limiting our generalizations. Also, participants self-reported their vaping status, which limited the causal inference and may introduce recall bias. Specifications for those who vaped, such as amount of nicotine, wattage, and other substances were not reported. Therefore, our findings may not extrapolate to others who vape with varying amounts of nicotine, different wattages, and other aspects regarding vape devices. Additionally, this was an acute investigation and did not allow for an examination of potential chronic impacts of vaping on pulse wave characteristics. Lastly, simultaneous measures of blood pressure and PWV, as well as imaging the diameter of the carotid artery via ultrasound was not performed. As a result, the potential to account for the impact of blood pressure on PWV through biomechanical models such as exponential pressure-diameter (P-D) or Meinders and Hoeks [49] was not possible.

5 Conclusion

Vaping status and BF% did not impact pulse wave characteristics among college-aged females. The lack of differences may be due to similarities in baseline pulse wave characteristics between groups and/or the motivations behind vaping among young adults (i.e., to manage weight control). $High_{VF\%}$ among vapers led to greater BDBP, CDBP, and CMAP relative to vapers with $Moderate_{VF\%}$. Additionally, there was no impact of vaping status and VF% on other pulse wave characteristics, which may be attributed to greater peripheral vascular resistance, tone and/or similar PWV, AIx, and PP values among vapers with $High_{VF\%}$. BDBP and CDBP were greater among Low_{BMD} compared to $Moderate_{BMD}$, and PP was lower among Low_{BMD} compared to $Moderate_{BMD}$. BSBP and BDBP may share an inverse relationship with BMD, however, vaping status did not affect this relationship.

Abbreviations

AIx	Augmentation index
AIx 75	Augmentation index normalized to 75 beats per minute
AP	Augmentation pressure
BF%	Body fat percentage
BMD	Bone mineral density
BSBP	Brachial systolic blood pressure
BDBP	Brachial diastolic blood pressure
bpm	Beats per minute
CSBP	Central systolic blood pressure
CDBP	Central diastolic blood pressure

CMAP	Central mean arterial pressure
mmHg	Millimetres of mercury
m/s	Meters per second
PP	Pulse pressure
PWV	Pulse wave velocity
RHR	Resting heart rate
VF%	Visceral fat percentage

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Availability of Data
The data used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest
The authors declare no competing interests.

Ethical Approval
This investigation was approved by the universities institutional review board. Written consent was obtained for each participant.

Consent for Publication
All authors give consent for publication of these findings.

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References

1. Miech R, Leventhal A, Johnston L, et al. Trends in use and perceptions of nicotine vaping among us youth from 2017 to 2020. JAMA Pediatr. 2021;175:185–90.
2. Bullen C, Howe C, Laugesen M, et al. Electronic cigarettes for smoking cessation: a randomised controlled trial. Lancet. 2013;382:1629–37.
3. Cheng T. Chemical evaluation of electronic cigarettes. Tob Control. 2014;23:ii11-7.
4. Davidson M, Al-Hamdani M. An examination of the social perceptions and vaping preferences of young electronic nicotine delivery system users. Front Public Health. 2023;11:1150368.
5. Morean ME, Bold KW, Kong G, et al. High school students' use of flavored e-cigarette e-liquids for appetite control and weight loss. Addcit Behav. 2020;102:106–39.
6. Franzen KF, Willig J, Cayo Talavera S, et al. E-cigarettes and cigarettes worsen peripheral and central hemodynamics as well as arterial stiffness: a randomized, double-blinded pilot study. Vasc Med. 2018;23:419–25.
7. Fetterman JL, Keith RJ, Palmisano JN, et al. Alterations in vascular function associated with the use of combustible and electronic cigarettes. J Am Heart Assoc. 2020;9: e14570.
8. Chaumont M, Van De Borne P, Bernard A, et al. Fourth generation e-cigarette vaping induces transient lung inflammation and gas exchange disturbances: results from two randomized clinical trials. Am J Physiol Lung Cell Mol Physiol. 2019;316:L705–19.
9. Chaumont M, De Becker B, Zaher W, et al. Differential effects of e-cigarette on microvascular endothelial function, arterial stiffness and oxidative stress: a randomized crossover trial. Sci Rep. 2018;8:10378.
10. Echeagaray O, Savko C, Gallo A, Sussman M, et al. Cardiovascular consequences of vaping. Curr Opin Cardiol. 2022;37:227–35.
11. Gonzalez JE, Cooke WH. Acute effects of electronic cigarettes on arterial pressure and peripheral sympathetic activity in young nonsmokers. Am J Physiol Heart Circ Physiol. 2021;320:H248–55.
12. Rezk-Hanna M, Gupta R, Nettle CO, et al. Differential effects of electronic hookah vaping and traditional combustible hookah smoking on oxidation, inflammation, and arterial stiffness. Chest. 2022;161:208–18.
13. Strasser B, Arvandi M, Pasha EP, et al. Abdominal obesity is associated with arterial stiffness in middle-aged adults. Nutr Metab Cardiovasc Dis. 2015;25:495–502.
14. Anoop S, Misra A, Bhardwaj S, et al. High body fat and low muscle mass are associated with increased arterial stiffness in Asian Indians in North India. J Diabetes Complications. 2015;29:38–43.
15. Cote AT, Phillips AA, Harris KC, et al. Obesity and arterial stiffness in children: systematic review and meta-analysis. Arterioscler Thromb Vasc Biol. 2015;35:1038–44.
16. Vianna CA, Horta BL, Gonzalez MC, et al. Association of pulse wave velocity with body fat measures at 30 y of age. Nutrition. 2019;61:38–42.
17. Kim HL, Ahn DW, Kim SH, et al. Association between body fat parameters and arterial stiffness. Sci Rep. 2021;11:20536.
18. Hu W, Zhang H, Liu Z, et al. Relationship between adipose tissue distribution and arterial stiffness in HFpEF. Nutrition. 2022;102: 111726.
19. Lanza HI, Pittman P, Batshoun J. Obesity and cigarette smoking: extending the link to E-cigarette/vaping use. Am J Healh Behav. 2017;41:338–47.
20. Wilson OW, Bullen C, Duffey M, et al. The association between vaping and health behaviors among undergraduate college students in the United States. J Am Coll Health. 2022;72(5):1360–4.
21. World medical association declaration of Helsinki. JAMA. 2013;310(20):2191–4.
22. Hwang MH, Yoo JK, Kim HK, et al. Validity and reliability of aortic pulse wave velocity and augmentation index determined by the new cuff-based SphygmoCor Xcel. J Hum Hypertens. 2013;28:475–81.
23. Matsuzawa Y, Nakamura T, Shimomura I, et al. Visceral fat accumulation and cardiovascular disease. Obes Res. 1995;3:645S-647S.
24. Mertens IL, van Gaal LF. Overweight, obesity, and blood pressure: the effects of modest weight reduction. Obes Res. 2000;8:270–8.
25. Ramadan J, Barac-Nieto M. Low-frequency physical activity insufficient for aerobic conditioning is associated with lower body fat than sedentary conditions. Nutrition. 2001;17:255–9.
26. Snijder MB, Henry RM, Visser M, et al. Regional body composition as a determinant of arterial stiffness in the elderly: the Hoorn study. J Hypertens. 2004;22:2339–47.
27. Baba R, Koketsu M, Nagashima M, et al. Adolescent obesity adversely affects blood pressure and resting heart rate. Circ J. 2007;71:722–6.
28. Fox CS, Massaro JM, Hoffmann U, et al. Abdominal visceral and subcutaneous adipose tissue compartments: association with metabolic risk factors in the Framingham Heart Study. Circulation. 2007;116:39–48.
29. Lurbe E, Torro I, Garcia-Vicent C, et al. Blood pressure and obesity exert independent influences on pulse wave velocity in youth. Hypertension. 2012;60:550–5.
30. Kwok SY, So HK, Choi KC, et al. Resting heart rate in children and adolescents: association with blood pressure, exercise and obesity. Arch Dis Child. 2013;98:287–91.
31. Dua S, Bhuker M, Sharma P, et al. Body mass index relates to blood pressure among adults. N Am J Med Sci. 2014;6:89–95.
32. Hortmann K, Boutouyrie P, Locatelli JC, et al. Acute effects of high-intensity interval training and moderate-intensity continuous training on arterial stiffness in young obese women. Eur J Prev Cardiol. 2021;28:e7–10.
33. Peruzzi M, Biondi-Zoccai G, Carnevale R, et al. Vaping cardiovascular health risks: an updated umbrella review. Curr Emerg Hosp Med Rep. 2020;8:103–9.
34. Tsai M, Byun MK, Shin J, et al. Effects of e-cigarettes and vaping devices on cardiac and pulmonary physiology. J Physiol. 2020;598:5039–62.

35. Piñeiro B, Correa JB, Simmons VN, et al. Gender differences in use and expectancies of e-cigarettes: online survey results. Addict Behav. 2016;52:91–7.
36. Sanchez R, Ranjit N, Kelder SH, et al. Intention to lose weight and use electronic cigarettes among adolescents. Prev Med Rep. 2021;23: 101406.
37. Huang W, Shu L, Zhao H, et al. Association of the triglyceride to high-density lipoprotein ration and the visceral adiposity index with metabolic syndrome in diabetic susceptible population. Horm Metab Res. 2020;52:95–103.
38. Asuku AY, Danborno B, Abubakar SA, et al. Adiposity measures in metabolic syndrome among Hausas in Kano. Northern Nigeria Nigerian J Physiol Sci. 2019;34:17–25.
39. Han SJ, Fujimoto WY, Kahn SE, et al. Change in visceral adiposity is an independent predictor of future arterial pulse pressure. J Hypertens. 2018;36:299–305.
40. Noll G, Tschudi M, Nava E, et al. Endothelium and high blood pressure. Internat J Microcirc. 1997;17:273–9.
41. Haynes WG, Ferro CJ, O'Kane KP, et al. Systemic endothelin receptor blockage decreases peripheral vascular resistance and blood pressure in humans. Circulation. 1996;93:1860–70.
42. Franklin SS. Arterial stiffness and diastolic blood pressure: what is the connection? Artery Res. 2006;1:S1–6.
43. Nichols WW, Singh BM. Augmentation index as a measure of peripheral vascular diseases state. Curr Opin Cardiol. 2002;17:543–51.
44. Nichols WW, Denardo SJ, Wilkinson IB, et al. Effects of arterial stiffness, pulse wave velocity, and wave reflections on the central aortic pressure waveform. J Clin Hypertens. 2008;10:295–303.
45. Najjar SS, Scuteri A, Shetty V, et al. Pulse wave velocity is an independent predictor of longitudinal increase in systolic blood pressures and of incident hypertension in the Baltimore longitudinal study of aging. J Am Coll Cardiol. 2008;51:1377–83.
46. Lee HT, Shin J, Min SY, et al. The relationship between bone mineral density and blood pressure in the Korean elderly population: the Korea National Health and Nutrition Examination Survey, 2008–2011. Clin Exp Hypertens. 2015;37:212–7.
47. Cappuccio FP, Meilahn E, Zmuda JM, et al. High blood pressure and bone-mineral loss in elderly white women: a prospective study. Lancet. 1999;354:971–5.
48. Nicholson T, Scott A, Ede MN, et al. The impact of e-cigarette vaping and vapour constituents on bone health. J Inflamm. 2021;18:16.
49. Giudici A, Palombo C, Kozakova M, et al. Subject-specific pressure normalization of local pulse wave velocity: separating intrinsic from acute load-dependent stiffening in hypertensive patients. Front Physiol. 2022;12: 783457.

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