Received: 20 January 2022 | Revised: 14 March 2022 | Accepted: 28 March 2022

DOI: 10.1111/jch.14490

ORIGINAL ARTICLE

WILEY

# Immediate post-exercise blood pressure and arterial stiffness in hypertensive and normotensive older females

Eduardo C. Costa PhD[1,2] | Rodrigo A. V. Browne PhD[2] | Marcyo Câmara MPEd[2] | Geovani A. D. Macêdo MPEd[1] | Bruno E. B. Lucena MD[2] | Lauro C. Vianna PhD[3] | Todd A. Duhamel PhD[4,5]

[1]Department of Physical Education, Federal University of Rio Grande do Norte, Natal, Brazil

[2]Graduate Program in Health Sciences, Federal University of Rio Grande do Norte, Natal, Brazil

[3]NeuroVÁSQ˙- Integrative Physiology Laboratory, Faculty of Physical Education, University of Brasília, Brasília, Brazil

[4]Faculty of Kinesiology and Recreation Management, University of Manitoba, Winnipeg, Canada

[5]Institute of Cardiovascular Sciences, St. Boniface General Hospital Albrechtsen Research Centre, Winnipeg, Canada

**Correspondence**
Eduardo Caldas Costa, PhD, Federal University of Rio Grande do Norte, Department of Physical Education, University Campus, BR 101, Lagoa Nova, Natal, RN, Brazil 59.078-970.
Email: eduardo.caldas@ufrn.br; ecc.ufrn@gmail.com

**Funding information**
Fondation de l'Hôpital Saint-Boniface; Conselho Nacional de Desenvolvimento Científico e Tecnológico, Grant/Award Numbers: 306744/2019–8, 307293/2019–0, 427729/2018-1; Coordenação de Aperfeiçoamento de Pessoal de Nível Superior

## Abstract

Although it has been suggested that increased arterial stiffness is linked to exaggerated blood pressure (BP) from brief moderate exercise, it is not clear whether this occurs in older adults with and without hypertension. This study investigates whether the immediate post-exercise systolic BP following brief moderate exercise is associated with arterial stiffness in older females with different BP status. This cross-sectional study included 191 older females aged 60–80 years without known cardiovascular disease (CVD). Arterial stiffness was determined by aortic pulse wave velocity (aPWV). Systolic BP was measured before and immediately following a 3-min moderate walking test (stage 1 Bruce protocol). Specific quartile-based thresholds were used to define an exaggerated immediate post-exercise systolic BP for hypertensive and normotensive older females (quartile 4 as an exaggerated response). Traditional CVD risk factors were assessed (covariates). Older females from the highest quartile of immediate post-exercise absolute systolic BP showed higher aPWV compared to their peers from the lowest quartile ($\beta = .22$ m/s, $p = .018$). The quartile-based threshold to define the exaggerated post-exercise systolic BP was higher in hypertensive than in normotensive older females (174 vs. 172 mmHg). In summary, exaggerated immediate post-exercise systolic BP following a brief moderate exercise is associated with higher arterial stiffness in older females with different BP status.

KEYWORDS
aging, arterial compliance, exaggerated exercise blood pressure, exercise-induced hypertension, pulse wave velocity, vascular health

# 1 | INTRODUCTION

Exaggerated systolic blood pressure (BP) during brief light-moderate exercise (i.e., ≤5 metabolic equivalents [METs]) is associated with masked[1] and future hypertension,[2] impaired vascular health[3] and baroreflex sensitivity,[4] increased left ventricular mass,[5] cardiovascular events and mortality.[6] Thus, it has been suggested that exaggerated systolic BP during brief light-moderate exercise may be clinically useful to identify individuals with cardiac and/or vascular alterations linked to cardiovascular disease (CVD).[7] We recently demonstrated that exaggerated systolic BP immediately following a 3-min moderate exercise test was able to discriminate reduced arterial compliance,[8] which is a surrogate marker of arterial stiffness,[9] in normotensive middle-aged and older females. These findings suggest that immediate post-exercise systolic BP following a brief light-moderate test may also be clinically useful for identifying individuals at increased CVD risk. Nevertheless, it is currently unknown whether these findings could be extrapolated to patients with hypertension.

Impaired vascular structure and function, including increased arterial stiffness, has been suggested to be mechanistically linked to exaggerated systolic BP during brief light-moderate exercise.[3,6,10] However, it is not clear whether exaggerated immediate post-exercise systolic BP is linked to arterial stiffness in both hypertensive and normotensive older adults. Given that aging per se modifies the functional and structural characteristics of the vasculature,[11] studies investigating whether an exaggerated immediate post-exercise systolic BP is linked to arterial stiffness exclusively in this population are needed. In addition, although it is expected that the magnitude of exercise BP is higher in hypertensive than in normotensive individuals, no information is available comparing the immediate post-exercise systolic BP following a brief moderate exercise between hypertensive and normotensive older adults. This is particularly useful to clarify the need (or not) of specific thresholds of exaggerated immediate post-exercise systolic BP for hypertensive and normotensive older adults. From a clinical perspective, the identification of specific thresholds for hypertensive and normotensive older adults could help to better identify individuals for a more comprehensive CVD risk screening. Therefore, this study investigated the association of immediate post-exercise systolic BP following a 3-min moderate walking test and arterial stiffness in older females with different BP status. We hypothesized that the immediate post-exercise systolic BP would be associated with arterial stiffness in older females with different BP status.

# 2 | METHODS

## 2.1 | Study design

This cross-sectional study was conducted at the Federal University of Rio Grande do Norte between June 2018 and December 2019. It is reported in accordance with the STROBE statement.[12] This study was approved by the Research Ethics Board of the Onofre Lopes University Hospital (protocol 2.603.422/2018) and conducted in accordance to the Declaration of Helsinki. All participants were informed about the study procedures and gave written informed consent.

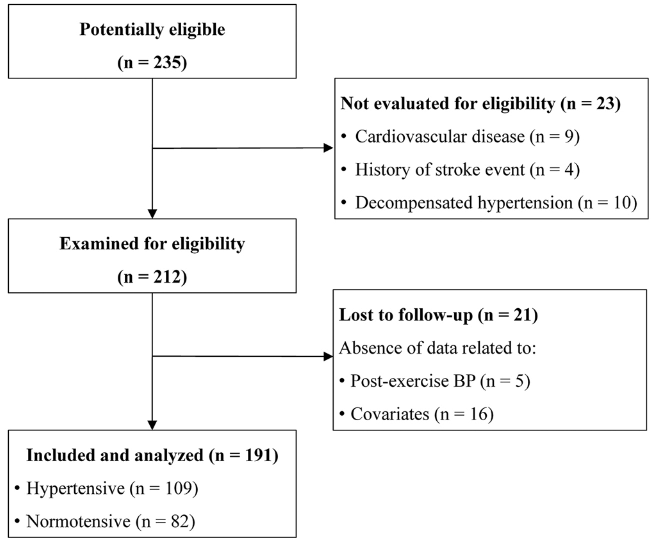


**FIGURE 1** Study flowchart. BP, blood pressure

## 2.2 | Participants

Community-dwelling older females aged 60–80 years were included in this study. They were recruited by advertisements on radio, TV, e-flyers in social media sites, health care units, and older adult community centers. The inclusion criteria were: (i) no history of known CVD or major cardiovascular events (e.g., acute myocardial infarction, stroke, coronary artery disease, arrhythmias, or peripheral vascular disease); (ii) no muscle, joint or bone injury which limits the ability to perform exercise; (iii) no acute diabetes- or hypertension-related decompensation (i.e., glycemia ≥ 300 mg/dl; BP ≥ 160/105 mmHg). Figure 1 shows the flowchart of this study.

## 2.3 | Arterial stiffness

A Brazilian version of the Mobil-O-Graph 24 h PWA Monitor (IEM, Stolberg, Germany), the Dyna–Mapa AOP (Cardios, São Paulo, Brazil), was used to measure aortic pulse wave velocity (aPWV). The aPWV obtained from this noninvasive device has been validated by comparing it with the aPWV obtained from the gold standard, invasive intra-aortic catheter method,[13,14] and from the noninvasive applanation tonometry.[15–17] aPWV was assessed before the 3-min moderate walking test in the left arm with the participant in a supine position after 10 min resting in a quiet and temperature-controlled room (24–26°C). Four consecutive measurements were obtained with 1-min interval between each one in following the manufacturer's instructions. The mean value of aPWV (m/s) obtained from the last three measurements was considered for data analysis.

### 2.4 | 3-min moderate walking test and immediate post-exercise blood pressure

The participants performed a 3-min walking test on a treadmill (RT 150 G3, Movement, Pompéia, Brazil) at an intensity equivalent to stage 1 Bruce protocol (speed: 2.7 km/h; grade: 10%; 5 METs). Before and immediately following the 3-min moderate walking test, BP was measured using a validated oscillometric device (HEM-780-E, Omron, Kyoto, Japan)[18] with the participants seated on a chair positioned ~1 m from the treadmill. Before the test, the BP was measured in triplicate with 1-min interval between each measure after 5 min resting. The average value of the last two measures was considered for data analysis.[19] Immediate post-exercise BP measure was taken within ~30 s following the 3-min moderate walking test.

### 2.5 | Covariates

The following additional information was obtained from the participants from a face-to-face interview: age, race, education, smoking history, medication use for hypertension, diabetes, and dyslipidemia. Bodyweight (kg) and height (m) were measured, and body mass index (BMI) was calculated as weight (kg) divided by the square of height in meters (kg/m$^2$). Body fat percentage was measured using a dual-energy X-ray absorptiometry (GE Healthcare Lunar Prodigy Advance, USA). Blood samples were collected following a 12-h overnight fasting period by venipuncture in order to assess total cholesterol, HDL-cholesterol, LDL-cholesterol, triglycerides, and fasting glucose. LDL-cholesterol was determined using the Friedewald formula: (total cholesterol – [HDL + triglycerides/5]). All biochemical assays were determined using commercial kits (Diagnostic Labtest-SA, São Paulo, Brazil) by the colorimetric method (Labtest, Labmax Plenno, Minas Gerais, Brazil). The Framingham risk score for CVD was calculated using the following criteria: age, sex, smoking, BMI, systolic BP, medication use for hypertension and diabetes.[20] Based on Framingham risk score, the participants were classified as low (<10%), moderate (≥10% and <20%) and high (≥20%) risk for CVD.[20] Frailty phenotype was determined according to Fried criteria[21]: low physical activity, weakness (low grip strength), slowness (slow walking speed), self-reported exhaustion, and unintentional weight loss. The participants were classified as robust (0 Fried criteria), prefrail (1-2 Fried criteria), and frail (3+ Fried criteria).

### 2.6 | Statistical analysis

A generalized linear or gamma model was used to compare the continuous data between the immediate post-exercise BP quartiles. Fisher's exact test was used to compare the categorical data between the immediate post-exercise BP quartiles. Continuous and categorical data were expressed as mean ± standard deviation (SD) and absolute and relative frequency, respectively. The generalized linear model was applied to examine the coefficient estimate ($\beta$) and its 95% Wald confidence intervals (CI) for aPWV using the following predictors (models): (a) per-unit increase every 1, 5, 10, 15, or 20 mmHg in immediate post-exercise absolute systolic BP; (b) per-unit increase every 1, 5, 10, 15, or 20 mmHg in absolute change in immediate post-exercise systolic BP; (c) quartiles of immediate post-exercise absolute systolic BP (Quartile 1 as reference); (d) quartiles of absolute change in immediate post-exercise systolic BP (Quartile 1 as reference). The models were adjusted for all the following potential confounders: age, race, body fat percentage, resting systolic BP, HDL-cholesterol, total cholesterol, diabetes lowering medication, antihypertensive medication, smoking status, and Fried frailty phenotype. Of note, the quartile 4 of the immediate post-exercise BP was considered as an exaggerated BP response. The linear or gamma distribution model for each model was defined by the normality of the residuals in the normal Q-Q plot and/or by the lower value of Akaike Information Criterion (AIC). The Omnibus test was performed to assess the goodness of fit for the models. The significance level was set at $p < .05$. Statistical procedures were performed using IBM SPSS Statistics for Win/v.27.0 (IBM Corp., Armonk, NY).

## 3 | RESULTS

### 3.1 | Sample characteristics

Table 1 shows the characteristics of the participants. A total of 191 older females were included in this study (57.1% hypertensive; 42.9% normotensive; Figure 1). A total of 18.3% of the cohort had postsecondary education and 57.6% lived with their partner. Most participants were overweight/obese (63.8%) and had moderate/high CVD risk based on Framingham risk score (67.0%).

### 3.2 | Association of immediate post-exercise absolute BP with arterial stiffness

Figure 2 and Table 2 show the coefficient estimates for aPWV according to quartiles of immediate post-exercise absolute systolic BP. Older females from the quartiles 4 showed higher aPWV values ($\beta = .22$ m/s, $p = .018$) compared to their peers from quartile 1 (reference group). No differences in aPWV values were observed from quartiles 2 and 3 compared to those from quartile 1 ($p > .05$). Table 2 also shows the coefficient estimates for aPWV according to per-unit increase in immediate post-exercise absolute systolic BP. There was a trend toward a positive association of per-unit increase in immediate post-exercise absolute systolic BP with aPWV ($\beta = .00$ m/s for 1 mmHg; $\beta = .01$ m/s for 5 mmHg; $\beta = .03$ m/s for 10 mmHg; $\beta = .04$ m/s for 15 mmHg; $\beta = .05$ m/s for 20 mmHg; $p = .089$). In addition, it was tested the moderating effect of hypertension on the association of immediate post-exercise absolute systolic BP (quartiles and per-unit increase) with aPWV. No moderating effect of hypertension was observed in these models ($p > .05$).

**TABLE 1** Characteristics of the older females ($n = 191$)

| | Mean ± SD or *n* (%) |
|---|---|
| Age, years | 65.8 ± 5.3 |
| Living with partner, *n* (%) | 110 (57.6) |
| Post-secondary education, *n* (%) | 35 (18.3) |
| *Pardo*/Black, *n* (%) | 119 (62.3) |
| White, *n* (%) | 72 (37.7) |
| Ex-smokers/smokers, *n* (%) | 73 (38.2) |
| Pre-frail/frail, *n* (%) | 118 (61.8) |
| Six-minute walk test, m | 484 ± 67 |
| Body fat, % | 43.6 ± 5.1 |
| Body mass index, kg/m2 | 28.9 ± 4.6 |
| Fasting glucose, mg/dl | 109.4 ± 29.3 |
| Triglycerides, mg/dl | 150.9 ± 76.7 |
| HDL-cholesterol, mg/dl | 47.9 ± 12.6 |
| LDL-cholesterol, mg/dl | 133.2 ± 44.0 |
| Total cholesterol, mg/dl | 207.9 ± 45.2 |
| Diabetes medication, *n* (%) | 47 (24.6) |
| Lipid-lowering medication, *n* (%) | 62 (32.5) |
| Antihypertensive medication, *n* (%) | 109 (57.1) |
| Monotherapy | 48 (44.0) |
| Combination therapy | 61 (56.0) |
| Calcium channel blockers | 10 (9.2) |
| Diuretics | 47 (43.1) |
| Angiotensin II receptor blockers | 85 (78.0) |
| ACE inhibitors | 9 (8.3) |
| Beta-blockers | 31 (28.4) |
| Resting SBP, mmHg | 125.1 ± 14.2 |
| Resting DBP, mmHg | 70.1 ± 8.5 |
| Resting PP, mmHg | 55.0 ± 10.6 |
| Immediate post-exercise SBP, mmHg | 159.2 ± 22.2 |
| Change in immediate post-exercise SBP, mmHg | 34.3 ± 17.7 |
| Aortic pulse wave velocity, m/s | 9.4 ± 1.0 |
| Framingham risk score, n (%) | |
| Low risk (< 10%) | 63 (33.0) |
| Moderate risk (≥10% and <20%) | 93 (48.7) |
| High risk (≥20%) | 35 (18.3) |

*Note*: Data are shown as mean ± SD or absolute (*n*) and relative (%) frequencies.
Abbreviations: ACE, angiotensin-converting-enzyme; BP, blood pressure; DBP, diastolic blood pressure; HDL, high-density lipoprotein; LDL, low-density lipoprotein; PP, pulse pressure; SBP, systolic blood pressure.

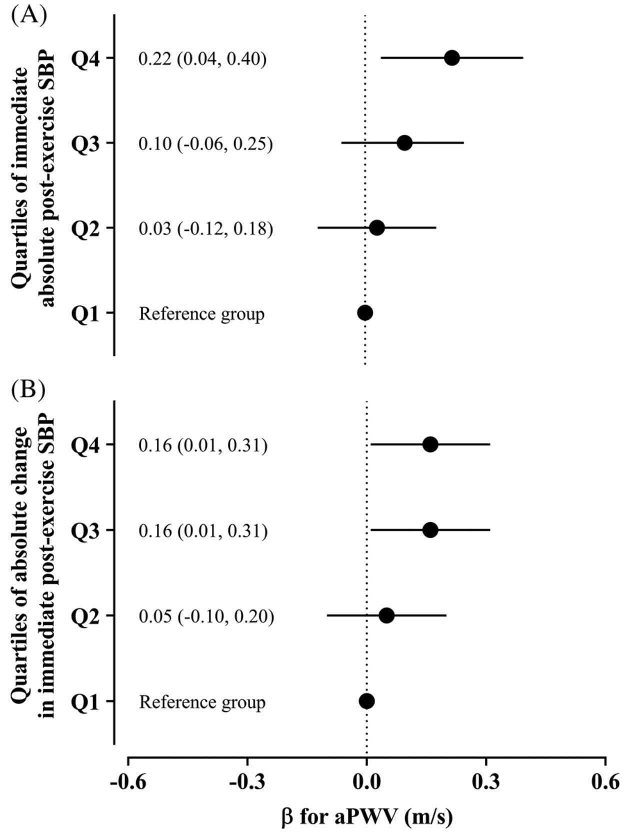


**FIGURE 2** Coefficient estimates ($\beta$) and its 95% Wald confidence interval (CI) for aortic pulse wave velocity (aPWV) according to quartiles of immediate post-exercise absolute systolic blood pressure (panel A) and to quartiles of absolute change in immediate post-exercise systolic blood pressure (panel B) of older females ($n = 191$). Analysis adjusted for age, race, smoking status, resting systolic blood pressure, body fat percentage, HDL-cholesterol, total cholesterol, diabetes medication, antihypertensive medication, and Fried frailty phenotype. Goodness of fit of the model: $p < 0.001$ in the Omnibus test

## 3.3 | Association of absolute change in immediate post-exercise BP with arterial stiffness

Figure 2 and Table 3 show the coefficient estimates for aPWV according to quartiles of absolute change in immediate post-exercise systolic BP. Older females from quartiles 3 ($\beta = .16$ m/s, $p = .031$) and 4 ($\beta = .16$ m/s, p = .033) showed higher aPWV values compared to their peers from quartile 1 (reference group). No differences in aPWV values were observed from the quartile 2 compared to those from quartile 1 ($p > .05$). Table 3 also show the coefficient estimates for aPWV according to per-unit increase in absolute change in immediate post-exercise systolic BP. There was a trend toward a positive association of per-unit increase in absolute change in immediate post-exercise systolic BP with aPWV ($\beta = .00$ m/s for 1 mmHg; $\beta = .01$ m/s for 5 mmHg; $\beta = .03$ m/s for 10 mmHg; $\beta = .04$ m/s for 15 mmHg; $\beta = .06$ m/s for 20 mmHg; $p = .077$). In addition, it was tested the moderating effect of hypertension on the association of absolute change in immediate post-exercise systolic BP (quartiles and per-unit increase) with aPWV. No moderating effect of hypertension was observed in these models ($p > .05$).

**TABLE 2** Coefficient estimates for pulse wave velocity according to quartiles of immediate post-exercise absolute systolic blood pressure of older females ($n = 191$)

| | aPWV, m/s | | |
|---|---|---|---|
| | $\beta$[a] | 95% Wald CI | *p* |
| Post-exercise SBP (per-mmHg increase) | | | |
| 1 mmHg | .00 | .00, .01 | .089 |
| 5 mmHg | .01 | .00, .03 | .089 |
| 10 mmHg | .03 | .00, .06 | .089 |
| 15 mmHg | .04 | -.01, .09 | .089 |
| 20 mmHg | .05 | -.01, .11 | .089 |
| Post-exercise SBP (per quartile) | | | |
| Q1 HT ≤ 146 mmHg; NT ≤ 142 mmHg | Ref. | | |
| Q2 HT 147–162 mmHg; NT 143–153 mmHg | .03 | −.12, .18 | .711 |
| Q3 HT 163–173 mmHg; NT 154–171 mmHg | .10 | −.06, .25 | .242 |
| Q4 HT ≥ 174 mmHg; NT ≥ 172 | .22 | .04, .40 | **.018** |

*Note*: Data are shown as coefficient estimates ($\beta$), and 95% Wald confidence interval (CI).
Bold values indicate significance at $p < .05$.
Abbreviations: aPWV, aortic pulse wave velocity; Q, quartile; SBP, systolic blood pressure.
[a]Analysis adjusted for age, race, smoking status, resting systolic blood pressure, body fat percentage, HDL-cholesterol, total cholesterol, diabetes medication, antihypertensive medication, and Fried frailty phenotype. Goodness of fit of the model: $p < .001$ in Omnibus test.

**TABLE 3** Coefficient estimates for pulse wave velocity according to quartiles of absolute change in immediate post-exercise systolic blood pressure of older females ($n = 191$)

| | aPWV, m/s | | |
|---|---|---|---|
| | $\beta$[a] | 95% Wald CI | *p* |
| Δ post-exercise SBP (per-mmHg increase) | | | |
| 1 mmHg | .00 | .00, .01 | .077 |
| 5 mmHg | .01 | .00, .03 | .077 |
| 10 mmHg | .03 | .00, .06 | .077 |
| 15 mmHg | .04 | .00, .09 | .077 |
| 20 mmHg | .06 | -.01, .12 | .077 |
| Δ post-exercise SBP (per quartile) | | | |
| Q1 HT ≤ 24 mmHg; NT ≤ 23 mmHg | .00 | Reference | |
| Q2 HT 25–34 mmHg; NT 24–31 mmHg | .05 | −.10, .20 | .512 |
| Q3 HT 35–47 mmHg; NT 32–42 mmHg | .16 | .01, .31 | **.031** |
| Q4 HT ≥ 48 mmHg; NT ≥ 43 mmHg | .16 | .01, .31 | **.033** |

*Note*: Data are shown as coefficient estimates ($\beta$), and 95% Wald confidence interval (CI).
Bold values indicate significance at p < .05.
Abbreviations: aPWV, aortic pulse wave velocity; HY, hypertensive; NT, normotensive; Q, quartile.; SBP, systolic blood pressure.
[a]Analysis adjusted for age, race, smoking status, resting systolic blood pressure, body fat percentage, HDL-cholesterol, total cholesterol, diabetes medication, antihypertensive medication, and Fried frailty phenotype. Goodness of fit of the model: $p < .001$ in Omnibus test.

### 3.4 | Sample characteristics according to quartiles of immediate post-exercise systolic BP

Table 4 shows the differences among the participants from quartiles 1–4 regarding the immediate post-exercise absolute systolic BP. Those with higher immediate post-exercise systolic BP presented with a higher resting systolic and diastolic BP, and pulse pressure, and had a higher prevalence of postsecondary education compared to the participants of lower immediate post-exercise BP ($p < .05$). Table 5 shows the differences among the participants from quartiles 1–4 regarding the absolute change in immediate post-exercise systolic BP. Those with higher immediate post-exercise BP (quartile 4) had a lower prevalence of postsecondary education compared to the participants in the other quartiles ($p < .05$). No differences were observed in the other variables among the quartiles ($p > .05$).

**TABLE 4** Characteristics of the older females according to quartiles of immediate post-exercise absolute systolic blood pressure ($n = 191$)

| | Quartile 1 | Quartile 2 | Quartile 3 | Quartile 4 | *p* |
|---|---|---|---|---|---|
| *N*(%) | 48 (25.1) | 50 (26.2) | 48 (25.1) | 45 (23.6) | |
| Age, years | 65.5 ± 5.1 | 66.1 ± 4.8 | 65.6 ± 6.3 | 65.8 ± 4.8 | .951 |
| Living with partner, *n* (%) | 25 (52.1) | 33 (66.0) | 26 (54.2) | 26 (57.8) | .519 |
| Post-secondary education, *n* (%) | 33 (68.8) | 42 (84.0) | 38 (79.2) | 43 (95.6)[a,c] | **.009** |
| *Pardo*/Black, *n* (%) | 27 (56.3) | 32 (64.0) | 28 (58.3) | 32 (71.1) | .454 |
| White, *n* (%) | 21 (43.8) | 18 (36.0) | 20 (41.7) | 13 (28.9) | |
| Ex-smokers/smokers, *n* (%) | 20 (41.7) | 17 (34.0) | 19 (39.6) | 17 (37.8) | .886 |
| Pre-frail/Frail, *n* (%) | 29 (60.4) | 29 (58.0) | 32 (66.7) | 28 (62.2) | .845 |
| Six-minute walk test, m | 485 ± 69 | 483 ± 63 | 485 ± 74 | 483 ± 62 | .997 |
| Body fat, % | 43.6 ± 5.1 | 43.8 ± 4.5 | 42.8 ± 6.1 | 44.4 ± 4.5 | .505 |
| Body mass index, kg/m2 | 28.6 ± 5.2 | 29.5 ± 4.5 | 28.4 ± 5.2 | 29.0 ± 3.5 | .678 |
| Fasting glucose, mg/dl | 108.0 ± 27.6 | 107.9 ± 23.7 | 107.3 ± 33.7 | 115.0 ± 31.7 | .533 |
| Triglycerides, mg/dl | 140.8 ± 56.7 | 158.7 ± 76.1 | 147.3 ± 68.1 | 156.6 ± 101.8 | .525 |
| HDL-cholesterol, mg/dl | 46.9 ± 10.5 | 47.1 ± 14.5 | 49.0 ± 13.7 | 48.8 ± 11.1 | .762 |
| LDL-cholesterol, mg/dl | 131.8 ± 45.6 | 125.2 ± 44.6 | 137.6 ± 37.4 | 139.1 ± 48.0 | .365 |
| Total cholesterol, mg/dl | 204.0 ± 46.1 | 200.6 ± 45.6 | 212.6 ± 38.6 | 215.3 ± 50.0 | .315 |
| Diabetes medication, *n* (%) | 11 (22.9) | 11 (22.0) | 13 (27.1) | 12 (26.7) | .930 |
| Lipid-lowering medication, *n* (%) | 11 (22.9) | 20 (40.0) | 17 (35.4) | 14 (31.1) | .322 |
| Antihypertensive medication, *n* (%) | 27 (56.3) | 29 (58.0) | 28 (58.3) | 25 (55.6) | .991 |
| Resting SBP, mmHg | 114 ± 12 | 123 ± 11[a] | 128 ± 12[a] | 136 ± 12[a,b,c] | **<.001** |
| Resting DBP, mmHg | 65 ± 7 | 70 ± 7[a] | 71 ± 8[a] | 75 ± 9[a,b] | **<.001** |
| Resting PP, mmHg | 49 ± 10 | 53 ± 10 | 57 ± 10[a] | 61 ± 9[a,b] | **<.001** |
| Immediate post-exercise SBP, mmHg | 132 ± 12 | 153 ± 6[a] | 165 ± 5[a,b] | 189 ± 12[a,b,c] | **<.001** |
| Change in immediate post-exercise SBP, mmHg | 18 ± 13 | 30 ± 12[a] | 38 ± 11[a,b] | 53 ± 15[a,b,c] | **<.001** |
| Pulse wave velocity, m/s | 9.1 ± 1.1 | 9.4 ± .9 | 9.5 ± 1.2 | 9.8 ± .9[a] | **.004** |
| Framingham risk score, *n* (%) | | | | | |
| Low risk (<10%) | 21 (43.8) | 16 (32.0) | 17 (35.4) | 9 (20.0) | .080 |
| Moderate risk (≥10% and <20%) | 24 (50.0) | 25 (50.0) | 19 (39.6) | 25 (55.6) | |
| High risk (≥20%) | 3 (6.3) | 9 (18.0) | 12 (25.0) | 11 (24.4) | |

*Note*: Data are shown as mean ± SD or absolute (*n*) and relative (%) frequencies.
Bold values indicate significance at $p < .05$.
Abbreviations: BP, blood pressure; DBP, diastolic blood pressure; HDL, high-density lipoprotein; LDL, low-density lipoprotein; PP, pulse pressure; Quartile 2: immediate post-exercise absolute systolic BP 147–162 mmHg for hypertensive and 143–153 mmHg for normotensive; Quartile 3 immediate post-exercise absolute systolic BP 163–173 mmHg for hypertensive and 154–171 mmHg for normotensive; Quartile 4: immediate post-exercise absolute systolic BP ≥ 174 mmHg for hypertensive and ≥172 mmHg for normotensive.; SBP, systolic blood pressure. Quartile 1: immediate post-exercise absolute systolic BP ≤ 146 mmHg for hypertensive and ≤ 142 mmHg for normotensive.
[a]Different from quartile 1 ($p < .05$).
[b]Different from quartile 2 ($p < .05$).
[c]Different from quartile 3 ($p < .05$).

## 4 | DISCUSSION

This study investigated the association between immediate post-exercise systolic BP following the 3-min moderate walking test and arterial stiffness in older females with different BP status. The main finding confirms that the exaggerated immediate post-exercise systolic BP was associated with higher aPWV in both hypertensive and normotensive older females. Thus, our results support the idea that exaggerated immediate post-exercise systolic BP is mechanistically linked to arterial stiffness in older females with different BP status, independent of other established CVD risk factors.

A reduction of the elastic component (elastin) and an increase in the inelastic component (collagen) mainly in the large conduit arteries are associated with increased arterial stiffness. In addition, increased sympathetic activity[22] and endothelial dysfunction mainly in muscular arteries are also associated with increased arterial stiffness.[9,23] Older

**TABLE 5** Characteristics of the older females according to quartiles of absolute change in immediate post-exercise systolic blood pressure ($n = 191$)

| | Quartile 1 | Quartile 2 | Quartile 3 | Quartile 4 | p |
|---|---|---|---|---|---|
| *N*(%) | 53 (27.7) | 45 (23.6) | 47 (24.6) | 46 (24.1) | |
| Age, years | 66.3 ± 5.8 | 65.0 ± 5.2 | 64.6 ± 5.2 | 67.1 ± 4.5 | .071 |
| Living with partner, *n* (%) | 28 (52.8) | 28 (62.2) | 24 (51.1) | 30 (65.2) | .424 |
| Post-secondary education, *n* (%) | 10 (18.9) | 11 (24.4) | 12 (25.5) | 2 (4.3)[a,b,c] | **.032** |
| *Pardo*/Black, *n* (%) | 32 (60.4) | 25 (55.6) | 29 (61.7) | 33 (71.7) | .444 |
| White, *n* (%) | 21 (39.6) | 20 (44.4) | 18 (38.3) | 13 (28.3) | |
| Ex-smokers/smokers, *n* (%) | 20 (37.7) | 16 (35.6) | 19 (40.4) | 18 (39.1) | .969 |
| Pre-frail/Frail, *n* (%) | 33 (62.3) | 28 (62.2) | 29 (61.7) | 28 (60.9) | 1.000 |
| Six-minute walk test, m | 485 ± 65 | 488 ± 69 | 491 ± 70 | 470 ± 64 | .423 |
| Body fat, % | 43.1 ± 4.5 | 43.2 ± 5.3 | 43.3 ± 6.3 | 45.0 ± 3.9 | .248 |
| Body mass index, kg/m2 | 28.6 ± 5.1 | 28.5 ± 4.2 | 28.7 ± 5.0 | 29.7 ± 4.1 | .554 |
| Fasting glucose, mg/dl | 107.9 ± 26.4 | 110.0 ± 25.7 | 106.9 ± 33.2 | 113.2 ± 31.9 | .617 |
| Triglycerides, mg/dl | 155.1 ± 78.0 | 145.8 ± 53.9 | 139.0 ± 75.0 | 163.0 ± 94.4 | .341 |
| HDL-cholesterol, mg/dl | 46.8 ± 11.5 | 47.2 ± 14.4 | 50.1 ± 13.9 | 47.7 ± 10.3 | .579 |
| LDL-cholesterol, mg/dl | 126.6 ± 38.7 | 138.6 ± 50.4 | 133.4 ± 43.1 | 135.5 ± 44.4 | .547 |
| Total cholesterol, mg/dl | 199.8 ± 38.7 | 211.8 ± 50.9 | 208.6 ± 44.9 | 212.8 ± 46.9 | .451 |
| Diabetes medication, *n* (%) | 12 (22.6) | 12 (26.7) | 9 (19.1) | 14 (30.4) | .612 |
| Lipid-lowering medication, *n* (%) | 13 (24.5) | 18 (40.0) | 15 (31.9) | 16 (34.8) | .431 |
| Antihypertensive medication, *n* (%) | 30 (56.6) | 25 (55.6) | 27 (57.4) | 27 (58.7) | .994 |
| Resting SBP, mmHg | 127 ± 15 | 125 ± 15 | 123 ± 13 | 124 ± 14 | .611 |
| Resting DBP, mmHg | 70 ± 8 | 71 ± 8 | 69 ± 8 | 70 ± 9 | .635 |
| Resting PP, mmHg | 57 ± 12 | 54 ± 11 | 55 ± 10 | 54 ± 10 | .485 |
| Immediate post-exercise SBP, mmHg | 141 ± 18 | 153 ± 15[a] | 162 ± 14[a,b] | 182 ± 18[a,b,c] | **<.001** |
| Change in immediate post-exercise SBP, mmHg | 14 ± 9 | 28 ± 3[a] | 39 ± 4[a,b] | 58 ± 9[a,b,c] | **<.001** |
| Aortic pulse wave velocity, m/s | 9.5 ± 1.2 | 9.3 ± 1.0 | 9.3 ± 1.0 | 9.7 ± .9 | .107 |
| Framingham risk score, *n* (%) | | | | | |
| Low risk (<10%) | 16 (30.2) | 18 (40.0) | 15 (31.9) | 14 (30.4) | .756 |
| Moderate risk (≥10% and <20%) | 27 (50.9) | 19 (42.2) | 21 (44.7) | 26 (56.5) | |
| High risk (≥20%) | 10 (18.9) | 8 (17.8) | 11 (23.4) | 6 (13.0) | |

*Note*: Data are shown as mean ± SD or absolute (*n*) and relative (%) frequencies.
Bold values indicate significance at $p < .05$.
Abbreviations: BP, blood pressure; DBP, diastolic blood pressure; HDL, high-density lipoprotein; LDL, low-density lipoprotein; PP, pulse pressure; Quartile 2: absolute change in immediate post-exercise systolic BP 25–34 mmHg for hypertensive and 24–31 mmHg for normotensive; Quartile 3 absolute change in immediate post-exercise systolic BP 35–47 mmHg for hypertensive and 32–42 mmHg for normotensive; Quartile 4: absolute change in immediate post-exercise systolic BP ≥ 48 mmHg for hypertensive and ≥ 43 mmHg for normotensive.; SBP, systolic blood pressure. Quartile 1: absolute change in immediate post-exercise systolic BP ≤ 24 mmHg for hypertensive and ≤ 23 for normotensive.
[a]Different from quartile 1 ($p < .05$).
[b]Different from quartile 2 ($p < .05$).
[c]Different from quartile 3 ($p < .05$).

adults are more susceptible to the above-mentioned structural and functional impairments in their vascular system.[9] In our study, both hypertensive and normotensive older females in the highest quartile of the immediate post-exercise systolic BP showed the highest aPWV values. Thus, an exaggerated systolic BP even following a 3-min moderate exercise is likely partially explained by stiffer large conduit arteries (i.e., aorta) as a result of structural remodeling. In addition, we do not rule out that impaired vascular function (i.e., flow-mediated dilation) may explain the exaggerated immediate post-exercise systolic BP which occurred in the older females with the highest aPWV values. Data from the Framingham Heart Study (53% females; 59 ± 9 years; 24% with hypertension) support our findings, showing that exercise BP at stage 2 of the Bruce protocol was associated with increased carotid-femoral PWV and impaired flow-mediated dilation, independent of other established CVD risk factors.[3] Independent of the resting BP values, our findings suggest that older females with increased arterial stiffness may have exaggerated BP during daily physical activities performed at a moderate intensity. As arterial stiffness and BP have a bidirectional relationship,[24,25] exaggerated, repetitive BP load on the vasculature, even during brief moderate physical activities, may create a vicious cycle contributing to further increase arterial stiffness in older females who already have stiffer arteries.

From a clinical perspective, older females with an exaggerated immediate post-exercise systolic BP should be considered for more comprehensive CVD risk screening, including a vascular health assessment. There is no well-established threshold to define what defines an exaggerated systolic BP for submaximal exercise intensities. Our findings indicate that the threshold to define an exaggerated immediate post-exercise systolic BP was 2 mmHg higher in hypertensive than in normotensive older females. Hypertensive older females with immediate post-exercise systolic BP ≥ 174 mmHg and normotensive older females with immediate post-exercise systolic BP ≥ 172 mmHg showed .22 m/s higher aPWV values compared to their hypertensive (≤146 mmHg) and normotensive (≤142 mmHg) peers with the lowest immediate post-exercise systolic BP, respectively. We have previously reported that normotensive females aged 55+ years with exaggerated post-exercise systolic BP following a 3-min moderate step-test (≥65 mmHg; highest quartile) showed increased odds ratios for reduced large (2.67, 1.03–6.94) and small (2.27, 1.22–4.21) arterial compliance compared to those with immediate post-exercise systolic BP ≤ 140 mmHg (lowest quartile). In addition, every 10 mmHg increase in immediate post-exercise systolic BP was associated with an odds ratio of 1.17 (1.04–1.31) and 1.25 (1.06–1.47) for reduced small and large arterial compliance, respectively.[8] Interestingly, the quartile-based threshold to define an exaggerated immediate post-exercise systolic BP was 7 mmHg lower in our previous study involving middle-aged and older Canadian normotensive females aged 55+ years (≥165 mmHg) compared to the present study involving older Brazilian females aged 60–80 years (≥172 mmHg). In normotensive individuals, a systolic BP to submaximal intensities (5–7 METs) varying from 150 to 180 mmHg is associated with masked and future hypertension.[7] A systolic BP threshold for submaximal intensities in hypertensive individuals associated with CVD risk factors, including arterial stiffness, and adverse events is unknown. Therefore, future studies should address this question.

As stated by Schultz and colleagues,[7] there is a need to develop normative data in order to define a specific threshold to characterize what constitutes an exaggerated BP for exercise at submaximal intensities, which may optimize the clinical use of BP response to brief light-moderate exercise tests or BP response to early stages of maximal exercise tests. It should be highlighted that a previous meta-analysis of longitudinal studies including 46,314 individuals observed a better prognostic role of exercise BP at moderate exercise intensity than at maximal exercise intensity to predict adverse CVD events and mortality.[6] We and others[8] argue that the assessment of BP response to brief light-moderate exercise test has advantages compared to a maximal exercise test, such as: (i) it reflects the cardiovascular stress imposed by most daily activities[6]; (ii) it is more palatable for unfit and older adults[8]; (iii) it is safe and time-efficient for initial screening at unsupervised settings[8]; (iv) it has greater accuracy due to less artifact noise.[26] In addition, post-exercise BP measurement allows a more standardized procedure and the use of both auscultatory and oscillometric methods. Therefore, immediate post-exercise BP following a 3-min moderate exercise test, such as step-test[8] or treadmill walking test, seems to be a feasible approach to identify individuals with exaggerated BP response to daily physical activities who may have an increased CVD risk.

This study has limitations. As a cross-sectional study, it is not possible to establish causality for the observed associations between immediate post-exercise systolic BP and arterial stiffness. The study included older females aged 60–80 years. Thus, our findings should be interpreted with caution and are not transferable to older females aged 80+ years or to older males. The external load (treadmill speed and grade) was designed to elicit a moderate intensity (5 METs) response, similar to daily physical activities. However, as we did not assess the heart-rate response (internal load) at the end of the 3-min walking test, it is not possible to confirm if all older females reached a moderate intensity effort. Even though the BP measure was taken within ~30 s following the 3-min walking test, this may not have captured the peak exercise systolic BP. On the other hand, this procedure may have increased the accuracy of BP measurement.

## 5 | CONCLUSIONS

Exaggerated immediate post-exercise systolic BP following a 3-min moderate walking test is associated with higher arterial stiffness in older females with different BP status. From a clinical perspective, the thresholds of immediate post-exercise systolic BP for brief moderate exercise associated with higher arterial stiffness are ≥174 mmHg (Δ ≥ 48 mmHg) and ≥172 mmHg (Δ 43 ≥ mmHg) for hypertensive and normotensive older females, respectively.

### ACKNOWLEDGMENTS

The authors would like to thank the older adults who volunteered to participate in this study. We thank Alana Monteiro, Daniel Borges, Daniel Cruz, Daniel Schwade, Fábio Coelho, Ludmila Cabral, Raíssa de Melo, and Ronildo Paulo for their support on the data collection. This study was partially supported by the Brazilian Council for Scientific and Technological Development (CNPq; 427729/2018-1). ECC is supported by a research productivity grant from the CNPq (306744/2019–8). RAVB, MC and GADM are supported by graduate scholarships (PhD and MSc) from the Brazilian Coordination of Improvement of Higher Education Personnel (CAPES). LCV is supported by a research productivity grant from the CNPq (307293/2019–0). TAD is supported by a St. Boniface Hospital Research Foundation women's heart health operating grant.

### CONFLICT OF INTEREST

Authors have no conflicts of interest to disclose.

### AUTHOR CONTRIBUTION

Eduardo C. Costa, Lauro C. Vianna and Todd A. Duhamel contributed to the study conception and design. Material preparation and data collection were performed by Rodrigo A. V. Browne, Marcyo Câmara, Geovani A. D. Macêdo and Bruno E. B. Lucena. Data analysis and interpretation were performed by Eduardo C. Costa, Rodrigo A. V. Browne and Lauro C. Vianna. The first draft of the manuscript was written by Eduardo C. Costa, Rodrigo A. V. Browne and Lauro C. Vianna and all authors commented on previous versions of the manuscript. All authors revised the manuscript and approved the final version.

## ORCID

*Eduardo C. Costa PhD* https://orcid.org/0000-0003-2807-7109
*Rodrigo A. V. Browne PhD* https://orcid.org/0000-0003-3005-247X
*Lauro C. Vianna PhD* https://orcid.org/0000-0002-5747-0295
*Todd A. Duhamel PhD* https://orcid.org/0000-0001-8467-4800

## REFERENCES

1. Schultz MG, Picone DS, Nikolic SB, Williams AD, Sharman JE. Exaggerated blood pressure response to early stages of exercise stress testing and presence of hypertension. *J Sci Med Sport*. 2016; 19(12): 1039-1042. https://doi.org/10.1016/j.jsams.2016.04.004.
2. Holmqvist L, Mortensen L, Kanckos C, Ljungman C, Mehlig K, Manhem K. Exercise blood pressure and the risk of future hypertension. *J Hum Hypertens*. 2012; 26(12): 691-695. https://doi.org/10.1038/jhh.2011.99.
3. Thanassoulis G, Lyass A, Benjamin EJ, et al. Relations of exercise blood pressure response to cardiovascular risk factors and vascular function in the Framingham Heart Study. *Circulation*. 2012; 125(23): 2836-2843. https://doi.org/10.1161/CIRCULATIONAHA.111.063933.
4. Sharman JE, Boutouyrie P, Perier M-C, et al. Impaired baroreflex sensitivity, carotid stiffness, and exaggerated exercise blood pressure: a community-based analysis from the Paris Prospective Study III. *Eur Heart J*. 2018; 39(7): 599-606. https://doi.org/10.1093/eurheartj/ehx714.
5. Kokkinos P, Pittaras A, Narayan P, Faselis C, Singh S, Manolis A. Exercise capacity and blood pressure associations with left ventricular mass in prehypertensive individuals. *Hypertension*. 2007; 49(1): 55-61. https://doi.org/10.1161/01.HYP.0000250759.71323.8b.
6. Schultz MG, Otahal P, Cleland VJ, Blizzard L, Marwick TH, Sharman JE. Exercise-induced hypertension, cardiovascular events, and mortality in patients undergoing exercise stress testing: a systematic review and meta-analysis. *Am J Hypertens*. 2013; 26(3): 357-366. https://doi.org/10.1093/ajh/hps053.
7. Schultz MG, La Gerche A, Sharman JE. Blood pressure response to exercise and cardiovascular disease. *Curr Hypertens Rep*. 2017; 19(11): 89. https://doi.org/10.1007/s11906-017-0787-1.
8. Costa EC, Boreskie KF, Scott Kehler D, et al. Immediate post-exercise blood pressure and arterial compliance in middle-aged and older normotensive females: a cross-sectional study. *Sci Rep*. 2020; 10(1): 9205. https://doi.org/10.1038/s41598-020-66104-8.
9. Townsend RR, Wilkinson IB, Schiffrin EL, et al. Recommendations for improving and standardizing vascular research on arterial stiffness: a scientific statement from the American heart association. *Hypertension*. 2015; 66(3): 698-722. https://doi.org/10.1161/HYP.0000000000000033.
10. Tzemos N, Lim PO, Mackenzie IS, MacDonald TM. Exaggerated exercise blood pressure response and future cardiovascular disease. *J Clin Hypertens*. 2015; 17(11): 837-844. https://doi.org/10.1111/jch.12629.
11. Lacolley P, Regnault V, Segers P, Laurent S. Vascular smooth muscle cells and arterial stiffening: relevance in development, aging, and disease. *Physiol Rev*. 2017; 97(4): 1555-1617. https://doi.org/10.1152/physrev.00003.2017.
12. vonElm E, Altman DG, Egger M, et al. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *Epidemiology*. 2007; 18(6): 800-804. https://doi.org/10.1097/EDE.0b013e3181577654.
13. Hametner B, Wassertheurer S, Kropf J, Mayer C, Eber B, Weber T. Oscillometric estimation of aortic pulse wave velocity. *Blood Press Monit*. 2013; 18(3): 173-176. https://doi.org/10.1097/MBP.0b013e3283614168.
14. Papaioannou TG, Karageorgopoulou TD, Sergentanis TN, et al. Accuracy of commercial devices and methods for noninvasive estimation of aortic systolic blood pressure a systematic review and meta-analysis of invasive validation studies. *J Hypertens*. 2016; 34(7): 1237-1248. https://doi.org/10.1097/HJH.0000000000000921.
15. Hoshide S, Komori T, Ogata Y, Eguchi K, Kario K. Evaluation of central blood pressure in an asian population: comparison between brachial oscillometry and radial tonometry methods. *Pulse*. 2018; 6(1-2): 98-102. https://doi.org/10.1159/000484442.
16. Weber T, Wassertheurer S, Rammer M, et al. Validation of a Brachial cuff-based method for estimating central systolic blood pressure. *Hypertension*. 2011; 58(5): 825-832. https://doi.org/10.1161/HYPERTENSIONAHA.111.176313.
17. Weiss W, Gohlisch C, Harsch-Gladisch C, Tölle M, Zidek W, van derGiet M. Oscillometric estimation of central blood pressure. *Blood Press Monit*. 2012; 17(3): 128-131. https://doi.org/10.1097/MBP.0b013e328353ff63.
18. Coleman A, Steel S, Freeman P, deGreeff A, Shennan A. Validation of the Omron M7 (HEM-780-E) oscillometric blood pressure monitoring device according to the British Hypertension Society protocol. *Blood Press Monit*. 2008; 13(1): 49-54. https://doi.org/10.1097/MBP.0b013e3282cb57b6.
19. Malachias M, Souza W, Plavnik F, et al. 7th Brazilian Guideline of Arterial Hypertension: chapter 2 - Diagnosis and Classification. *Arq Bras Cardiol*. 2016; 107(3). https://doi.org/10.5935/abc.20160152.
20. D'Agostino RB, Vasan RS, Pencina MJ, et al. General cardiovascular risk profile for use in primary care: the Framingham Heart Study. *Circulation*. 2008; 117(6): 743-753. https://doi.org/10.1161/CIRCULATIONAHA.107.699579.
21. Fried LP, Tangen CM, Walston J, et al. Frailty in older adults: evidence for a phenotype. *J Gerontol A Biol Sci Med Sci*. 2001; 56(3): M146-56. https://doi.org/10.1093/gerona/56.3.m146.
22. Nardone M, Floras JS, Millar PJ. Sympathetic neural modulation of arterial stiffness in humans. *Am J Physiol Heart Circ Physiol*. 2020; 319(6): H1338-H1346. https://doi.org/10.1152/ajpheart.00734.2020.
23. Zieman SJ, Melenovsky V, KassDA. Mechanisms, pathophysiology, and therapy of arterial stiffness. *Arterioscler Thromb Vasc Biol*. 2005; 25(5): 932-943. https://doi.org/10.1161/01.ATV.0000160548.78317.29.
24. Kaess BM, Rong J, Larson MG, et al. Aortic stiffness, blood pressure progression, and incident hypertension. *JAMA*. 2012; 308(9): 875-881. https://doi.org/10.1001/2012.jama.10503.
25. Mitchell GF. Arterial stiffness and hypertension: chicken or egg?. *Hypertension*. 2014; 64(2): 210-214. https://doi.org/10.1161/HYPERTENSIONAHA.114.03449.
26. Sharman JE, LaGerche A. Exercise blood pressure: clinical relevance and correct measurement. *J Hum Hypertens*. 2015; 29(6): 351-358. https://doi.org/10.1038/jhh.2014.84.

**How to cite this article:** Costa EC, Browne RAV, Câmara M, et al. Immediate post-exercise blood pressure and arterial stiffness in hypertensive and normotensive older females. *J Clin Hypertens*. 2022;24:704-712.
https://doi.org/10.1111/jch.14490