



The Pilates Method reduces blood pressure and increases respiratory strength and cardiorespiratory capacity in medicated hypertensive women

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Abstract

Purpose The escalating global cost of chronic diseases, linked to physical inactivity, underscores the need for effective interventions for conditions like hypertension, heart disease, and reduced lung function. This study evaluated the impact of a 15-week Pilates Method (PM) exercise program on lung function, cardiorespiratory capacity, and blood pressure in medicated hypertensive women.

Methods This observational, longitudinal, before-and-after study involved 22 hypertensive women (median age 53 years) participating in 60-min PM sessions thrice weekly. Pre- and post-intervention assessments included anthropometry, respiratory muscle strength (measured throughout and one month post-intervention), spirometry, cardiopulmonary exercise testing, blood pressure, biochemical analysis, flexibility, and handgrip strength.

Results Significant improvements were observed in several anthropometric variables, with a large effect size on conicity index. Maximum inspiratory (MIP) and maximum expiratory pressure (MEP) increased post-PM, and no significant loss was observed one month after the end of the protocol. Almost all spirometric (except forced expiratory volume in the first second) and cardiopulmonary exercise variables increased post-PM, with maximal oxygen consumption (VO₂max) showing a large effect size. Furthermore, PM promoted a significant improvement in the majority of biochemical variables (except HDL), a significant reduction in 24-h and daytime systolic blood pressure with a large effect size, and improved flexibility and handgrip strength.

Conclusion The PM protocol elicited significant positive changes across a range of anthropometric, respiratory muscle strength, cardiopulmonary, and cardiovascular parameters in hypertensive women, highlighting its potential as an effective non-pharmacological management strategy for this population.

Keywords Exercise training · Hypertension · Respiratory function tests · VO₂max · Cholesterol · Glycemia

Introduction

Chronic Non-Communicable Diseases (NCDs) refer to a group of diseases that have long-term health consequences, require lengthy and time-consuming treatment, and can, in most cases, be prevented with lifestyle modification (Whelton et al. 2018; Arnett et al. 2019). According to the Pan

American Health Organization, NCDs represent 71% of the causes of death worldwide, and in the Americas region, cardiovascular diseases, diabetes, chronic obstructive pulmonary diseases, and systemic arterial hypertension (SAH) are among the ten leading causes of death (Pan American Health Organization).

Hypertension poses a significant risk for cardiovascular and cerebrovascular diseases and stands as the leading cause of premature death globally (Whelton et al. 2018; Barroso et al. 2021). In 2010, 31.1% (1.39 billion) of the global adult population was affected, and the prevalence of hypertension is significantly higher in low- and middle-income countries (31.5%) compared to high-income countries (28.5%) (Mills et al. 2016, 2020). From these data, it is estimated that

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hypertension is present in 600 million women, and approximately 23% of them are underdiagnosed, and undertreated (Chapman et al. 2023). Taken together, these findings highlight the need for improved awareness and management of hypertension, especially among women, to reduce premature mortality from cardiovascular diseases.

On the other hand, exercise training has been widely disseminated as a first-choice therapeutic tool for hypertensive patients (Whelton et al. 2018; Barroso et al. 2021). Most studies have demonstrated a reduction of -5.5 (95% CI, -8.1 to -2.8) mmHg in 24-h systolic arterial blood pressure (SBP), -3.8 (95% CI, -4.9 to -2.6) mmHg in diastolic arterial blood pressure (DBP) with aerobic exercise training, and 0.5 (95% CI, -1.1 to 2.1) mmHg and 0.5 (95% CI, -0.6 to 1.6) mmHg, respectively, in resistance exercise training, as demonstrated from the review of Saco-Ledo et al. (2020).

Physical activity is a strategy for individuals to improve conditions linked to the aging process, enhance cardiovascular protection against metabolic changes (Ruberti et al. 2021), improve affective dimensions and social belonging (Davis et al. 2021), and prevent and treat NCDs (Anderson and Durstine 2019).

Among the systematized physical exercise techniques, the Pilates Method (PM) has gained significant popularity. Developed by Joseph Pilates as a holistic approach to health and quality of life (Pereira et al. 2022), it is based on six key principles: breathing, concentration, control, centralization, precision, and rhythm (Gallagher et al. 1999; Lessen 2014; Delgado and Marco 2016). While theoretically considered a form of resistance exercise with well-documented benefits for skeletal muscle, emerging evidence suggests a crucial cardiorespiratory component (Lim and Yoon 2017; Fernández-Rodríguez et al. 2019).

In fact, various studies demonstrate the clinical benefits of PM, including reducing pain intensity in individuals with chronic low back pain (Wasser et al. 2017; Vera-Saura et al. 2024), weight reduction in obese individuals (Batrakoulis 2022), and reduced blood pressure (BP) in individuals with SAH (Martins-Meneses et al. 2015). However, to date, there is no record of the effects of PM practice on ventilatory variables and the cardiorespiratory capacity of hypertensive individuals.

We propose that the Pilates methodology, through its emphasis on conscious and controlled diaphragmatic breathing (Gallagher et al. 1999) potentially enhancing vagal tone and improving baroreceptor sensitivity, along with the prioritization of continuous, flowing movements (Delgado and Marco 2016) that impose a sustained metabolic demand and may improve endothelial function, and the integrated engagement of multiple muscle groups eliciting a sustained cardiovascular response (Fernández-Rodríguez et al. 2019) and promoting nitric oxide release, may also contribute to a reduction in BP (Martins-Meneses et al. 2015) and

improvements in cardiorespiratory parameters (Fernández-Rodríguez et al. 2019).

This study is important as research suggests a relationship between SAH and pulmonary function (Schnabel et al. 2011b). According to Hüzmeli et al. (2024), the respiratory muscles of hypertensive individuals perform ventilatory dynamics with excessive force due to activation of the metaboreflex. Furthermore, several studies have demonstrated that cardiorespiratory capacity is reduced in hypertensive individuals compared to normotensive individuals (Cornelissen and Fagard 2005; Kokkinos and Myers 2010), and the reduction in this capacity is associated with increased mortality. Therefore, we hypothesize that hypertensive women could improve lung function and cardiorespiratory capacity when practicing PM, as this training, among other aspects, also works on ventilatory aspects. We also hypothesize that respiratory muscle strength will remain improved compared to baseline levels even one month after the cessation of the PM training.

Methods

Experimental approach to the problem

This is an observational, longitudinal, before-and-after, single-arm study. This model was important for the present study as it allowed the evaluation, in the same individuals, of the effects of PM on respiratory capacity, blood pressure and biochemical variables. All volunteers participated in training with the PM and carried out pre- and post-training assessments.

Subjects

The study was approved by the Ethics Committee of the Federal University of São Paulo (CEP Unifesp 3.423.613). Furthermore, the study was registered on the Brazilian Registry of Clinical Trials (ReBEC) platform under registration RBR-78b6zky. The subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki as reflected in a priori approval by the CEP Unifesp.

The sample size was calculated using the difference between the two means of the dependent group. For this purpose, the maximum inspiratory pressure (MIP) value from a similar study in the literature (Ferreira et al. 2013) in hypertensive individuals undergoing 8 weeks of inspiratory muscle training (82.7 ± 28.8 vs. 121.5 ± 21.8 cmH₂O, pre vs. post, respectively) were used as a basis, with a power of 80% and type 1 error of 5%. The calculation was carried out

using the sample calculator developed by researchers from Paulista State University (UNESP) (Lauris et al.), reaching a minimum N value of 15. However, we chose to include as many individuals as possible who wished to participate, as the study was conducted during the COVID-19 pandemic, which could lead to a high percentage of dropouts. Therefore, the final N consisted of 22 women.

The inclusion criteria were: (a) be a hypertensive woman and on medication of any class; (b) be aged between 30 and 59 years by the end of the intervention; (c) be sedentary for at least six months before starting the training protocol; (d) have a body mass index of up to 30 kg/m²; (e) not use contraceptives or hormone replacement therapy; (f) have medical authorization to practice physical exercise; (g) not present musculoskeletal disease that could compromise partial or total execution of the proposed exercises; (h) not have any other disease that could compromise the cardiovascular, respiratory, or metabolic response to exercise; (i) not have diabetes mellitus; (j) not be a smoker or drinker; (k) not have damage to a target organ, such as nephropathy and heart disease, and (g) agree to volunteer for the project.

The exclusion criteria were: (a) change in drug treatment during the study; (b) absence from more than 25% of the 42 PM sessions.

Procedures

Exercise training

The exercise training was designed based on the exercises in the PM repertoire, combining ground exercise techniques with rotation on the four methods' leading equipment: Universal Reformer, Cadillac, Chair, and Barrel.

Before the intervention, the volunteers underwent a two-week adaptation period to familiarize themselves with PM principles and equipment.

The same researcher taught the intervention period, which lasted 15 weeks, with 60-min sessions held three times per week, totaling 42 training sessions for all volunteers. The sessions took into account the guiding and original principles of PM and had a cumulative progression, i.e., the volunteers repeated the exercises from the previous session and performed new exercises according to the evolutionary process of learning the repertoire for each individual. Furthermore, the sessions were structured at three different times: (a) start of class, consisting of stretching, breathing exercises, and pre-Pilates; (b) PM exercise sequence, consisting of Pilates exercises on the floor or equipment, with a single series and repetitions that varied from 5 to 10, depending on the exercise; (c) finishing and calming down: exercises in a standing position.

All exercises alternated precision and fluidity, without pausing between them and with transitions relevant to the beginner level. The training intensity was controlled using the Borg Scale. From the 1st to the 8th week of training, the intensity adopted was 11 to 13, and from the 9th to the 14th week, the intensity progressed, going from 13 to 15 (Martins-Meneses et al. 2015). This increase in intensity was achieved by increasing spring tension, exercise progression or both.

Measurements

The same researcher with previous clinical experience assessed the measurements at standardized times for all volunteers in the pre- and post-intervention periods.

Height was assessed using a stadiometer (Profissional Sanny®, São Paulo, Brazil). Body mass was measured using a calibrated precision scale (Balmak model BF680, São Paulo, Brazil). Subsequently, the volunteers' body mass index (BMI) was calculated using mass and height. Waist and hip circumferences were measured using a stretch-resistant measuring tape. Subsequently, the waist-hip ratio was calculated by dividing the waist circumference by the hip circumference. Furthermore, using the waist circumference, weight, and height values, the conicity index of the volunteers was calculated, as indicated by Valdez (Valdez 1991).

The maximum inspiratory (MIP) and expiratory (MEP) pressures were evaluated using the Analog Manovacuumeter (Murenas Series, model MV0476-300, Minas Gerais, Brazil), coupled with a silicone line measuring 30 cm, connected to an exclusive adapter for pressure evaluation. The adapter with a 15 mm opening and 1 mm valve was used to prevent the production of significant pressure from the facial muscles.

Volunteers were seated in a chair with back support. Nasal obstruction was performed with a clip, preventing air passage, and volunteers were instructed to perform two tidal volume (TV) cycles. Subsequently, they were instructed to perform maximum expiration until residual volume (RV) (Black and Hyatt 1969; Tzelepis et al. 1994a, 1994b), followed by a maximum inspiration. The "7 mm air exhaust opening" was occluded at this time, and MIP was obtained.

The volunteers were instructed to perform two respiratory cycles on TV to assess MEP. After the last exhalation, they slowly inhaled until total lung capacity (TLC) (Black and Hyatt 1969; Leith and Bradley 1976), followed by a maximum forced expiration. At this point, the "7 mm air exhaust opening" was occluded with the researcher's finger, and the MEP was obtained.

MIP and MEP measurements were performed six times with one-minute intervals between them to avoid muscle fatigue. Considering a maximum difference of 10% in the values obtained, the most significant measurement

was noted as the maximum value (Black and Hyatt 1969; Evans and Whitelaw 2009). In total, seven assessments were carried out: the first, in the pre-intervention period; four assessments throughout the training protocol, with an interval of 15 days between them; the sixth assessment, post-intervention; and, finally, the seventh and last evaluation (“follow up”) one month after the end of training with PM to find out if the effects would persist.

Flow, volume, and lung capacity variables were quantified with a spirometer (Quark PFT, Italy) according to the criteria established by the American Thoracic Association (Ferris 1978). For the evaluation, the volunteers remained seated, initially resting for 10 min, and then performing the maneuvers in the same position. They were asked to keep their head in a neutral position to avoid a reduction or increase in initial forced expiratory flows due to changes in tracheal stiffness. All volunteers used the nose clip to prevent air from leaking through the nostrils.

During forced exhalation, the researcher encouraged the volunteers to maintain the effort for at least 6 s until the volume-pressure loop was formed, associating the visualization of the graph to aid the process. The reproducibility criterion adopted was at least three acceptable maneuvers with the two highest values of the first second of expiration (FEV1) and forced vital capacity (FVC) differing ≤ 0.15 L and peak expiratory flow (PEF) $< 10\%$ or 0.5 L (whichever is bigger).

The Cardiopulmonary Exercise Test (CEPT) was conducted in a cycle ergometer (Lode Corival CPET, Lode BV, Groningen, Netherlands) with electromagnetic braking.

Estimated maximal oxygen consumption ($\text{VO}_{2\text{max}}$) was calculated according to the American College of Sports Medicine (ACSM) recommendations. HR was monitored throughout the test by a 12-lead electrocardiogram (Quark C12x, COSMED, Pavonadi Albano, Italy). The first ventilatory threshold (LT) was determined using the gas exchange method by visually inspecting the inflection point of the VCO_2/VO_2 (V-slope method) and the ventilatory method (e.g., the first nonlinear increment of VE/VO_2 with simultaneous VE/VCO_2 stabilization) (Wasserman 2012). The second ventilatory threshold (RC) was identified through the ventilatory method, using VO_2 (VE/VO_2) and VCO_2 (VE/VCO_2) ventilatory equivalents (Wasserman 2012).

Metabolic, cardiovascular, and ventilatory responses were measured using a properly calibrated gas analyzer (Quark PFT, COSMED, Pavona di Albano Laziale, Italy). All tests were conducted at the same altitude, atmospheric pressure, and temperature (20 °C).

The protocol adopted was a ramp type with a rapid increase in load occurring constantly until exhaustion. In the resting phase, the following were evaluated: HR, BP, electrocardiogram, and subjective assessment of effort using the Borg scale for dyspnea and lower limbs.

The warm-up phase took place over 3 min at zero load. Subsequently, the load increase began lasting 8–12 min (an average of 10 min). The added applied power progressively increased according to the degree of fitness until the power referring to the $\text{VO}_{2\text{max}}$, which was estimated according to each volunteers' characteristics. All volunteers had increments of 10 W/min. Furthermore, the volunteer had to maintain a constant cycling speed, with a pedaling frequency between 50–60 revolutions per minute (rpm). Linear power increments were established for a linear increase in work rate over time. The following criteria were used to consider the maximum test: when the maximum HR (HR_{max}) was equal to or greater than 85% of that estimated for the age ($220 - \text{age}$) and/or gas exchange rate ($R \geq 1.00$; and/or when there was a plateau in VO_2 . Subsequently, the active recovery phase was carried out for 3 min at zero load.

Blood pressure (BP) was measured by an oscillometric device (Dyna-MAPA® ABP Monitor, Cardio Sistemas, São Paulo, Brazil), which was programmed to measure BP every 15 min during the day and every 30 min at night.

The device was placed on the volunteers' non-dominant arm before and after the intervention. Volunteers were instructed to carry out their daily activities as usual but to refrain from consuming alcohol while wearing the device. In addition, they were instructed to record their activity diary during the 24 h of monitoring. At the end of the period, all values recorded during 24 h of SBP, DBP and heart rate (HR) were calculated (24-h BP). In addition, the averages of the volunteers' waking (daytime BP) and sleeping periods (nighttime BP) were calculated. The nighttime period was considered to be from 10 pm to 6 am.

Regarding biochemical assessment, the volunteers were instructed to undergo a blood test, before and after the experimental period, in the same laboratory where they were accustomed, after fasting for 8 h to evaluate metabolic parameters at rest. Tests of fasting blood glucose, glycated hemoglobin (HbA1c), triglycerides (TG), total cholesterol (TC), and high density lipoprotein (HDL) and low density lipoprotein (LDL) fractions were requested.

In order to evaluate the flexibility of the trunk and lower limbs, the sit and reach test was performed using the bank of Wells (Cardiomed, Paraná, Brazil).

The handgrip strength test was carried out using the hydraulic handgrip dynamometer (Jamar®, Nottinghamshire, UK), following the protocol described by Adams (Beam and Adams 2023). In this protocol, the volunteer is positioned erect, with the head neutral, and the elbow at 180° (arm vertical) next to the body. The equipment's handle was adjusted so that the third phalanx was close to a right angle (90°).

The volunteers quickly exercised the grip, using maximum force, and maintained it for 8 s. Three grips were performed with each hand, alternately, with at least 30 s of rest

for the next grip of the same hand. The result was obtained by averaging the grips of each hand.

Statistical analysis

The statistical analysis used the Jamovi software version 2.3 for the Windows operating system. Data distribution was assessed using the Shapiro–Wilk test. In the case of parametric distribution, the Student's *t*-test for paired samples was used to analyze parametric data, the Cohens' *d* was used to calculate the effect size, and the results were expressed as mean $\pm$ standard deviation and 95% confidence interval (95% CI). The guidelines for interpreting Cohen's *d*, as proposed by Cohen (1988), are as follows: Small: *d* = 0.2; Medium: *d* = 0.5; Large: *d* = 0.8.

In the case of non-parametric distribution, the Wilcoxon signed-rank test for paired data was performed to assess the significance of the change, and the rank-biserial correlation was calculate to estimate the effect size. The results were expressed as the median and first and third quartiles. Guidelines for interpreting the magnitude of the rank-biserial correlation are as follows: Small: *r* = around 0.1 to 0.3; Medium: *r* = around 0.3 to 0.5; Large = *r* above 0.5.

Furthermore, a one-way repeated measures analysis of variance (ANOVA) with Tukey's post-hoc test was performed to analyze the variables evaluated throughout the training protocol (MIP and MEP).

The value of 5% was adopted as the limit for statistical significance ($p \leq 0.05$). The Fig. 1 was created using the GraphPad Prism 9.0 statistical package.

Results

Twenty-two women with a median age of 53 years were evaluated (Q1 = 49 and Q3 = 56, Table 1). Furthermore, angiotensin 1 receptor blockers were the most frequent medication among volunteers ($n = 13$, Rf = 59.1%), followed by beta-blockers ($n = 8$, Rf = 36.4%), as shown in Table 1.

Regarding anthropometric measurements (Table 2), all variables showed significant changes, except for body mass and waist-to-hip ratio. Importantly, the conicity index (CI) presented a significant difference, including a large effect size ($p = 0.01$ and $W = -0.706$). The volunteers' height was statistically different after the intervention period, showing an increase of 0.8 cm ($p < 0.001$, $W = 1$).

Concerning the assessment of respiratory muscle strength (Fig. 1), a significant difference was observed in pre- and post-intervention MIP (pre 43.18 ± 15.55 cmH₂O vs post 121.4 ± 24.74 cmH₂O, $p < 0.001$, 95% CI = 62.23 – 94.14) and pre and post-intervention MEP (pre 71 ± 15.21 cmH₂O vs post 136.82 ± 26.80 cmH₂O, $p < 0.001$, 95% CI = 48.92 – 81.98). At the end of the follow-up period, there was no significant loss of MIP (post 121.4

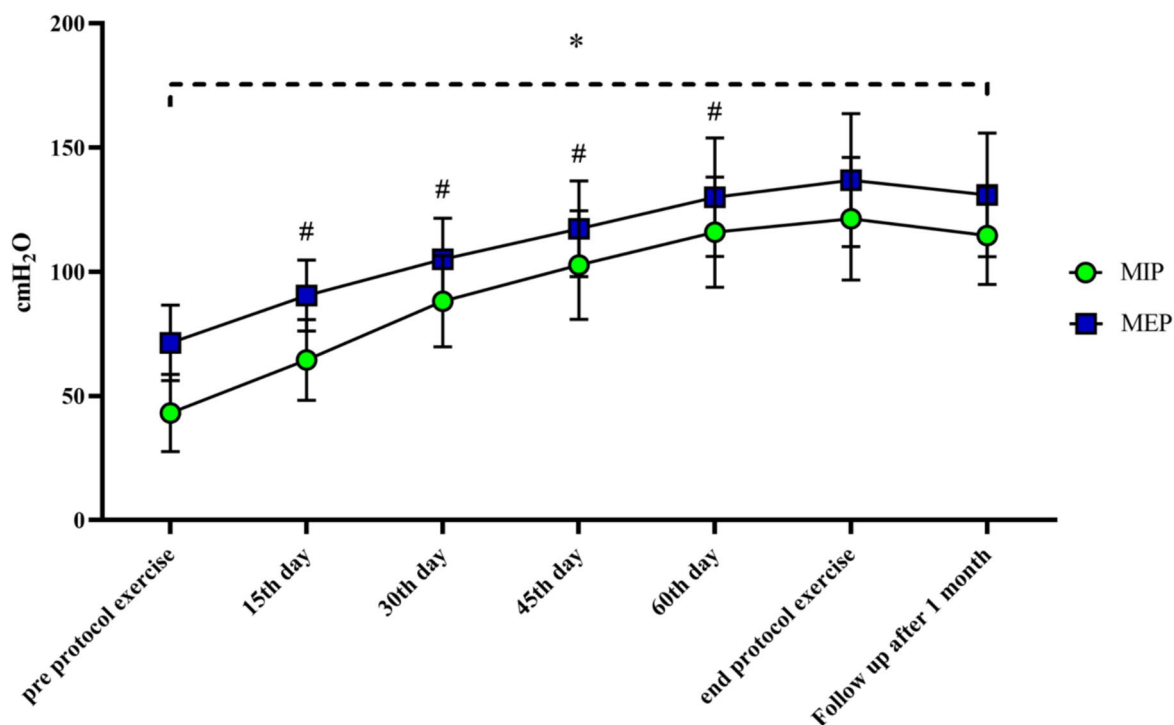


Fig. 1 Evolution of respiratory muscle strength throughout the training protocol and one month after the end of training. * $p \leq 0.05$ – vs Pre; # $p \leq 0.05$ – vs Previous assessment. MIP maximum inspiratory pressure; MEP maximum expiratory pressure

Table 1 Participant characteristics at baseline and antihypertensive medications used

	N	Median	Percentiles	
			25 th	75 th
Age	22	53.0	49.0	56.0
Body mass (Kg)	22	68.5	64.8	71.3
Height (cm)	22	159.0	156.0	160.4
BMI (kg/m ²)	22	27.3	25.9	29.3
Waist circumference (cm)	22	85.5	81.6	89.3
Hip circumference (cm)	22	104.0	99.3	105.9
Medicaments	N	%		
ACE inhibitors	2	9.1		
AT1 receptor blockers	13	59.1		
Beta blockers	8	36.4		
Calcium channel blockers	3	13.6		
Diuretics	5	22.7		

BMI body mass index; *ACE* angiotensin-converting enzyme; *AT1* angiotensin II receptor type 1

± 24.74 cmH₂O vs follow-up 114.54 ± 19.7 cmH₂O, $p = 0.32$, 95% CI = $-16.71 - 3.07$) and MEP (post 121.4 ± 24.74 cmH₂O vs follow up 130.9 ± 24.9 cmH₂O, $p = 0.30$, 95% CI = $-14.37 - 2.55$).

Furthermore, there was no significant increase in MIP and MEP on the 75 th day (end of the protocol) compared with the 60 th.

Spirometric variables are presented in Table 3. FEV1 was the only spirometric variable that did not show a significant difference when comparing the two periods. The remaining variables increased, exhibiting a medium (FVC) or large effect size (FEV1, PEF, FEV1/FVC, FEV25-75).

Cardiopulmonary assessment during exercise and ventilation (Table 4) showed significant difference in all variables when comparing the pre- and post-intervention periods.

Serum and cardiovascular variables, presented in Table 5, showed statistical differences in most variables except for HDL, nighttime SBP, 24-h DBP, and nighttime DBP values. Concerning SBP values, the median 24-h and daytime showed a significant reduction of 6 mmHg ($p \leq 0.001$, $W = -0.947$) and 5.5 mmHg ($p \leq 0.001$, $W = -0.979$), respectively, following the intervention. Regarding DBP, only the median of the daytime period showed a significant reduction ($p = 0.020$, $W = -0.683$).

The volunteers' lipid profile (Table 5) showed a lower post-intervention median value ($p < 0.001$ and $W = -0.929$), especially in those individuals in Q3 (pre = 170 mg/dL vs post = 140.5).

As observed in Table 6, PM practice contributed to increased flexibility and handgrip strength in hypertensive women.

Table 2 Anthropometric variables shown in median and quartiles

	Pre	Percentiles		Post	Percentiles		p	Effect Size
		25 th	75 th		25 th	75 th		
Body mass (kg)	68.45	64.8	71.3	67.5	65.0	71.6	0.355	-0.229
Height (cm)	159.0	156.0	160.4	159.8*	157.0	161.7	<.001	1.000
BMI (kg/m ²)	27.3	25.9	29.3	26.4*	25.6	28.7	0.005	-0.680
Waist circumference (cm)	85.5	81.6	89.3	84.2*	80.6	85.7	0.002	-0.781
Hip circumference (cm)	104.0	99.3	105.9	102.0*	97.50	106.1	0.005	-0.706
Waist:hip ratio (cm)	0.8	0.8	0.8	0.8	0.8	0.8	0.070	-0.543
Conicity index	1.44	1.40	1.49	1.43*	1.38	1.47	0.011	-0.706

* $p \leq 0.05$ – vs Pre

Table 3 Spirometric variables shown in mean and standard deviation

	Pre	Post	p	Effect Size	95% Confidence Interval	
					Lower	Upper
FVC (L)	2.93 ± 0.4	$3.05 \pm 0.36^*$	0.020	0.538	0.08	0.98
FEV1 (L)	2.38 ± 0.41	2.44 ± 0.34	0.125	0.341	-0.09	0.77
PEF (L/s)	5.77 ± 1.15	$6.58 \pm 0.90^*$	<.001	0.897	0.39	1.39
FEV1/FVC (%)	79.12 ± 7.71	$82.47 \pm 5.15^*$	0.001	0.800	0.31	1.27
FEV25-75 (%)	2.34 ± 0.86	$2.68 \pm 0.87^*$	<.001	0.995	0.47	1.50

* $p \leq 0.05$ – vs Pre. *FVC* forced vital capacity; *FEV1* forced expiratory volume in the first second; *PEF* peak expiratory flow; *FEV25-75* mean forced expiratory flow in the range of 25–75% of FVC

Table 4 Cardiopulmonary exercise test and ventilatory variables shown in median and quartiles

		Percentiles			Percentiles			
	Pre	25 th	75 th	Post	25 th	75 th	p	Effect Size
Cardiopulmonary Exercise Test								
VO ₂ (ml/min)	1205.0	1059.3	1396.5	1378.0*	1225.0	1461.0	<.001	0.850
VO ₂ /kg (ml/min/kg)	17.4	16.4	20.5	20.1*	18.2	22.2	<.001	0.921
PetO ₂ (mmHg)	116.0	112.3	117.0	118.0*	115.5	120.0	<.001	0.972
PetCO ₂ (mmHg)	38.0	36.3	39.0	35.5*	35.0	37.8	<.001	−0.936
VE/VO ₂	35.0	31.9	38.1	40.1*	35.7	42.4	<.001	0.858
VE/VCO ₂	30.8	29.6	33.1	33.0*	31.5	35.1	0.001	0.823
VE/VCO ₂ slope	27.9	26.4	29.8	26.4*	23.4	29.0	0.002	−0.747
OUES (ml/min/L/min)	1534.5	1350.5	1709.5	1646.5*	1528.8	1866.3	<.001	0.874
Power LT (watt)	42.5	31.3	45.0	60.0*	55.0	68.8	<.001	1.000
VO ₂ LT (ml/min)	793.0	686.3	838.5	936.5*	860.3	995.5	<.001	1.000
VO ₂ /Kg LT (ml/min/Kg)	11.2	10.3	12.3	14.2*	11.9	14.9	<.001	0.960
Power RC (watt)	80.0	70.0	90.0	102.5*	95.0	105.0	<.001	1.000
VO ₂ RC (ml/min)	1048.5	1009.8	1132.8	1300.5*	1146.8	1352.5	<.001	1.000
VO ₂ /Kg RC (ml/min/Kg)	16.3	15.3	17.2	19.1*	17.4	21.2	<.001	0.992
Ventilatory Variables								
VE (L/min)	45.5	37.0	49.4	49.1*	47.2	58.8	<.001	1.000
VE LT (L/min)	20.4	17.9	23.0	25.7*	24.1	28.7	<.001	0.992
VE RC (L/min)	33.1	30.9	36.9	44.4*	40.0	48.8	<.001	1.000
BR (%)	54.5	49.2	59.0	45.5*	37.2	54.7	0.001	−0.818
TV (L)	1.38	1.06	1.53	1.50*	1.25	1.67	<.001	0.834

* $p \leq 0.05$ – vs Pre. VO₂ = oxygen consumption, PetO₂ exhaled oxygen pressure; PetCO₂ exhaled carbon dioxide pressure; VE pulmonary ventilation; VCO₂ carbon dioxide production; OUES oxygen uptake efficiency slope; Power LT Power (load) at 1st ventilation threshold; Power RC Power (load) at 2nd ventilation threshold.; VE minute lung ventilation; LT 1st ventilation threshold; RC 2nd ventilation threshold; BR ventilatory reserve; TV tidal volume

Table 5 Cardiovascular and biochemical variables shown in median and quartiles

	Pre	Percentiles		Post	Percentiles		p	Effect Size
		25 th	75 th		25 th	75 th		
24-h SBP (mmHg)	120.0	115.0	124.8	114.0*	112.0	119.0	<.001	−0.947
Daytime SBP (mmHg)	122.0	117.0	129.0	116.5*	113.5	119.3	<.001	−0.979
Nighttime SBP (mmHg)	106.0	104.8	114.3	104.5	102.0	113	0.161	−0.362
24-h DBP (mmHg)	79.5	74.0	84.0	77.0	72.5	80.3	0.112	−0.444
Daytime DBP (mmHg)	81.0	77.8	86.8	79.0*	74.8	83.0	0.020	−0.683
Nighttime DBP (mmHg)	66.5	61.5	70.3	66.0	62.8	71.5	0.856	−0.053
HR (bpm)	73.0	64.7	81.5	69.0*	59.2	75.5	<.001	−0.866
Glycemia (mg/dL)	102.0	94.0	108.5	95.0*	89.2	102.7	0.013	−0.609
HbA1c (%)	5.65	5.50	6.00	5.40*	5.13	5.60	<.001	−0.939
TC (mg/dL)	225.0	198.0	248.5	198.5*	171.0	212.0	<.001	−0.922
TG (mg/dL)	141.5	101.2	188.7	119.0*	90.0	157.7	<.001	−0.822
HDL (mg/dL)	51.0	47.0	58.7	55.0	50.0	59.7	0.082	0.448
LDL (mg/dL)	152.5	117.5	170.0	116.0*	85.2	140.5	<.001	−0.929
TG/HDL	3.01	1.55	4.01	2.27*	1.38	3.06	<.001	−0.834
LDL/HDL	2.66	2.19	3.25	2.16*	1.62	2.39	<.001	−0.984

* $p \leq 0.05$ – vs Pre. SBP systolic blood pressure, DBP diastolic blood pressure, HR heart rate, HbA1c gly-cated hemoglobin, TC total cholesterol, TG triglycerides, HDL high density lipoprotein, LDL low density lipoprotein

Table 6 Physical performance variables shown in mean and standard deviation

	Pre	Post	p	Effect Size	95% Confidence Interval	
					Lower	Upper
Flexibility (cm)	20.3 ± 10.53	28.4 ± 9.19*	<.001	1.53	0.900	2.14
Right hand strength (kg)	22.7 ± 3.9	26.0 ± 3.94*	<.001	1.74	1.066	2.41
Left hand strength (kg)	21.3 ± 4.42	25.6 ± 3.29*	<.001	1.74	1.060	2.40

* $p \leq 0.05$ – vs Pre

Discussion

In this study, the initial hypothesis was confirmed since the hypertensive women who participated in the PM training protocol showed significant improvements in lung function and cardiorespiratory capacity, demonstrated by improvements in FVC, FEV1/FVC ratio, MIP, MEP, and all ergospirometric and ventilatory variables evaluated. Furthermore, BP values were significantly reduced after the training period and MIP and MEP remaining improved compared to baseline levels even one month after the cessation of the PM training.

According to Takase et al. (2023), lung function, FEV1, and FVC are inversely proportional to high BP values in hypertensive individuals. During the treatment of SAH, the use of antihypertensive drugs, especially beta-blockers, appears to be associated with a reduction in FVC. In contrast, the entire drug class seems to reduce the FEV1/FVC ratio (Schnabel et al. 2011a).

SAH and reduced lung function are known as risk markers for cardiovascular events and early death (Wang et al. 2018; Rethy et al. 2020; Takase et al. 2023). In this sense, PM training appears to have the potential to mitigate adverse events resulting from the use of antihypertensive drugs or SAH complications, as at the end of the protocol, there was an increase in FVC and the FEV1/FVC ratio.

It was previously described that PM exercises also act on the muscles involved in ventilatory dynamics, producing an increase in lung function after eight weeks of training in individuals with COVID-19 (Bagherzadeh-Rahmani et al. 2023). However, the significant increase in FEV1 was only observed by Bagherzadeh-Rahmani et al. (2023) in individuals discharged from the hospital at least one month prior due to COVID-19. Other studies, like this one, demonstrated that the increase in FEV1 was not significant (Jesus et al. 2015; Giacomini et al. 2016; Barbosa et al. 2024), suggesting that the result presented by Bagherzadeh-Rahmani et al. (2023) was probably due to recent hospital discharge. In any case, it is a topic that requires further studies.

Our findings demonstrate the effect of the PM on lung function, as respiratory muscle strength remained improved compared to the pre-experimental period even one month after the cessation of the PM protocol. We believe this result is attributable to the respiratory work consistently integrated

throughout all Pilates sessions. This respiratory engagement typically involves: emphasis on diaphragmatic breathing, coordination of breath with movement, controlled exhalation during exertion, focus on core engagement (Pilates and Miller 2009; Giacomini et al. 2016). This consistent and mindful integration of respiratory work within the PM sessions likely contributed to the sustained improvements in respiratory muscle strength observed in our study, even after the training period concluded.

This improvement in lung function contributed to improved cardiorespiratory capacity, as the volunteers showed significant improvements in all variables analysed in the ergospirometric test. To date, most publications and their discussions consider PM a type of resistance exercise (Martins-Meneses et al. 2015; Junges et al. 2015). However, based on the writings of Joseph Pilates, the repertoire, the practice of the method, and, primarily, the respiratory and cardiovascular work required, we believed that the method had a significant cardiorespiratory effect, which, in fact, was confirmed.

Our findings support Tinoco-Fernández et al. (2016), who conducted an observational study with a single group with pre- and post-intervention assessments on 45 sedentary adults aged 18–35 years (80% women) on cardiorespiratory function through VO_2max , VE/VCO_2 , HR, VE/VO_2 , VE/VCO_2 , and VE_{peak} . While they observed significant results in all variables, they performed a submaximal cardiorespiratory assessment, unlike our study, which evaluated all indices at maximal exercise. They used a protocol with a total intervention of 10 weeks, three times per week with 60-min classes and the Mat Pilates repertoire, at a basic level. In our program, the protocol was 15 weeks and used a combination of Mat Pilates and equipment.

Fernández-Rodríguez et al. (2019) carried out a systematic review with a meta-analysis of 10 eligible articles and a very heterogeneous population: healthy sedentary women, older women, adults, trained runners, patients with chronic stroke, and overweight and obese individuals aged between 18 and 66. They observed that PM increased VO_2max , with a medium effect size ($d = 0.51$) for the pre- and post-time-points, and improved cardiorespiratory fitness, regardless of the health status of the studied population.

Regarding the reduction of BP, in a study with hypertensive older adults, the authors demonstrated that at the end of 12 weeks of training with Mat Pilates, the individuals

presented an average reduction of 13 mmHg in SBP ($p = 0.019$, effect size = 0.568) and a reduction in DBP of 8 mmHg ($p = 0.037$, effect size 0.621) (Woramontri et al. 2024). A meta-analysis consisting of four randomized clinical trials and seven comparative studies demonstrated that PM training programs achieved significant reductions in SBP of -4.76 mmHg (95%CI: -6.55 to -2.97 , $p < 0.001$) and in DBP of -3.43 mmHg (95%CI: -4.7 to -2.49 , $p < 0.001$) (González-Devesa et al. 2024).

According to the authors, the likely mechanism explaining the reduction in BP would be the reduction of inflammatory and oxidative markers. Furthermore, PM's influence on ventilatory mechanics seems to contribute to the increase in nitric oxide bioavailability since aerobic exercises increase the tension in the artery walls and the synthesis of nitric oxide (Woramontri et al. 2024).

Furthermore, an alternative mechanism potentially explaining the positive effects of PM on cardiopulmonary variables is the improvement in autonomic modulation, as evidenced by the significant increases in SDNN, LF (ms^2), and SD2 indices following a PM program of at least 12 weeks (Cavina et al. 2021). According to Rahman et al. (2011), LF power reflect baroreflex function (Rahman et al. 2011).

The respiratory training characteristic of PM seems to be responsible for this effect too, as individuals with heart failure undergoing inspiratory muscle training showed an improvement in MIP ($+28.3$ cmH₂O, $p = 0.001$), VO₂max ($+4.5$ mL/min/kg, $p = 0.002$), and LF (Mello et al. 2012).

Regarding serum variables, although we observed a significant statistical difference in most markers at the end of the PM training protocol (Table 5), the main results of this study were the reduction of fasting plasma glucose levels to values within the normal range and the reduction of LDL to the cutoff point considered desirable in non-diabetic individuals. In the meta-analysis conducted by Chen et al., non-diabetic individuals did not show a significant reduction in glycemia ($p = 0.18$) and a significant reduction in LDL ($p = 0.00001$) (Chen et al. 2021). The result related to blood glucose may have occurred due to the lack of standardization of the PM technique used. In any case, there is an open debate as to whether the PM would be effective in controlling blood glucose and other metabolic markers.

Previous studies have shown that PM can lead to several benefits. Some authors have described that PM can increase handgrip strength (Martins-Meneses et al. 2015; Aibar-Almazán et al. 2022), while Pires et al. found that it provides greater flexibility and decreases the perception of effort after a single session (Pires et al. 2024). Furthermore, prior training with PM has been shown to help reduce the loss of range of motion in the postoperative period following cardiac bypass surgery (Pinto Souza et al. 2021).

Regarding anthropometric measurements, similar to this study, a previous study demonstrated that face-to-face or

online PM did not promote significant changes in BMI or the waist-to-hip ratio (Park et al. 2023). However, we found a slight reduction in the conicity index and abdominal circumference. According to Valdez et al., the advantage of using the conicity index instead of the waist-to-hip ratio is that other body dimensions are considered (Valdez et al. 1993).

Practical applications

Therefore, the 15-week intervention (42 sessions), with three times per week and 60 min per session of PM carried out on the ground and equipment demonstrated effectiveness in reducing SBP in controlled hypertensive women, in addition to contributing to increased cardiorespiratory capacity and respiratory muscle strength from the 15th day of training. Furthermore, in the one-month follow-up after the end of the experimental protocol, respiratory muscle strength remained greater than in the pre-intervention period.

Moreover, the PM protocol used improved height, BMI, waist and hip circumferences, conicity index, flexibility, and handgrip strength in the women evaluated in this study, in addition to biochemical variables such as fasting blood glucose, HbA1c, TC, TG, and LDL.

Thus, training with MP can be used as another strategy to improve the health of hypertensive women.

Author contribution RFB, DTR, and AM conceived and designed the research. RFB, DTR, and ACBB conducted the experiments. BR, VZD, and AM contributed with analytical tools. RFB, MFPG, ACBB, BR, and VZD analyzed the data. MFPG and AM wrote the manuscript. All authors read and approved the manuscript.

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Data availability The data generated during the current study are available from the corresponding author on reasonable request.

Declarations

Conflicts of interests The authors have no competing interests to declare that are relevant to the content of this article.

References

- Aibar-Almazán A, Martínez-Amat A, Cruz-Díaz D et al (2022) The influence of Pilates exercises on body composition, muscle strength, and gait speed in community-dwelling older women: a randomized controlled trial. *J Strength Cond Res* 36:2298–2305. <https://doi.org/10.1519/JSC.0000000000003790>
- Anderson E, Durstine JL (2019) Physical activity, exercise, and chronic diseases: a brief review. *Sports Med Health Sci*. <https://doi.org/10.1016/j.smhs.2019.08.006>

- Arnett DK, Blumenthal RS, Albert MA et al (2019) ACC/AHA Guideline on the primary prevention of cardiovascular disease: a report of the American College of Cardiology/American Heart Association task force on clinical practice guidelines. *Circulation*. <https://doi.org/10.1161/CIR.0000000000000678>
- Bagherzadeh-Rahmani B, Kordi N, Haghighi AH et al (2023) Eight weeks of Pilates training improves respiratory measures in people with a history of COVID-19: a preliminary study. *Sports Health* 15:710–717. <https://doi.org/10.1177/19417381221124601>
- Barbosa M, de Melo CA, Torres R (2024) The effects of adding a six-month Pilates exercise program to three months of traditional community-based pulmonary rehabilitation in individuals with COPD: a prospective cohort study. *Can J Respir Ther Rev Can Ther Respir*. <https://doi.org/10.29390/001c.117966>
- Barroso WKS, Rodrigues CIS, Bortolotto LA et al (2021) Brazilian guidelines of hypertension - 2020. *Arq Bras Cardiol*. <https://doi.org/10.36660/abc.20201238>
- Batrakoulis A (2022) Psychophysiological adaptations to Pilates training in overweight and obese individuals: a topical review. *Dis Basel Switz*. <https://doi.org/10.3390/diseases10040071>
- Beam W, Adams G (2023) Isometric (static) strength. In: *Exercise Physiologic Laboratory Manual*, 9th Edition. McGraw-Hill
- Black LF, Hyatt HRE (1969) Maximal respiratory pressures: normal values and relationship to age and sex. *Am Rev Dis*. <https://doi.org/10.1164/arrd.1969.99.5.696>
- Cavina AP, Silva NM, Biral TM et al (2021) Effects of 12-week Pilates training program on cardiac autonomic modulation: a randomized controlled clinical trial. *J Comp Eff Res* 10:1363–1372. <https://doi.org/10.2217/cer-2021-0195>
- Chapman N, Ching SM, Konradi AO et al (2023) (2023) Arterial hypertension in women: state of the art and knowledge gaps. *Hypertens Dallas Tex* 80:1140–1149. <https://doi.org/10.1161/HYPERTENSIONAHA.122.20448>
- Chen Z, Ye X, Xia Y et al (2021) Effect of Pilates on glucose and lipids: a systematic review and meta-analysis of randomized controlled trials. *Front Physiol* 12:641968. <https://doi.org/10.3389/fphys.2021.641968>
- Cohen J (1988) *Statistical power analysis for the behavioral sciences*. Routledge Academic, New York, NY
- Cornelissen VA (1979) Fagard RH (2005) Effects of endurance training on blood pressure, blood pressure-regulating mechanisms, and cardiovascular risk factors. *Hypertens Dallas Tex* 46:667–675. <https://doi.org/10.1161/01.HYP.0000184225.05629.51>
- Davis AJ, MacCarron P, Cohen E (2021) Social reward and support effects on exercise experiences and performance: Evidence from parkrun. *PLoS ONE*. <https://doi.org/10.1371/journal.pone.0256546>
- Delgado CP, Marco A de (2016) Método Pilates de condicionamento do corpo, 3a. Phorte
- Evans JA, Whitelaw WA (2009) The assessment of maximal respiratory mouth pressures in adults. *Respir Care* 54:1348–1359
- Fernández-Rodríguez R, Álvarez-Bueno C, Ferri-Morales A et al (2019) Pilates method improves cardiorespiratory fitness: a systematic review and meta-analysis. *J Clin Med*. <https://doi.org/10.3390/jcm8111761>
- Ferreira JB, Plentz RDM, Stein C et al (2013) Inspiratory muscle training reduces blood pressure and sympathetic activity in hypertensive patients: a randomized controlled trial. *Int J Cardiol* 166:61–67. <https://doi.org/10.1016/j.ijcard.2011.09.069>
- Ferris BG (1978) The american review of respiratory disease. *Epidemiol. Stand. Proj. II Recomm. Respir. Dis. Quest. Use Adults Child. Epidemiol. Res.* 7–57
- Gallagher SP, Kryzanowska R, Speleotis S (1999) *The Pilates method of body conditioning: introduction to the core exercises, illustrated edition*. Bainbridge Books
- Giacomini MB, da Silva AMV, Weber LM, Monteiro MB (2016) The Pilates method increases respiratory muscle strength and performance as well as abdominal muscle thickness. *J Bodyw Mov Ther* 20:258–264. <https://doi.org/10.1016/j.jbmt.2015.11.003>
- González-Devesa D, Varela S, Diz-Gómez JC, Ayán-Pérez C (2024) The efficacy of Pilates method in patients with hypertension: systematic review and meta-analysis. *J Hum Hypertens* 38:200–211. <https://doi.org/10.1038/s41371-024-00899-1>
- Hüzmeli İ, Katayıfçı N, Yalçın F, Hüzmeli ED (2024) Effects of different inspiratory muscle training protocols on exercise capacity, respiratory muscle strength, and health-related quality of life in patients with hypertension. *Int J Clin Pract* 2024:4136457. <https://doi.org/10.1155/2024/4136457>
- Jesus LT de, Baltieri L, Oliveira LG de, et al (2015) Efeitos do método Pilates sobre a função pulmonar, a mobilidade toracoabdominal e a força muscular respiratória: ensaio clínico não randomizado, placebo-controlado. *Fisioter. E Pesqui.*
- Junges S, Jacondino CB, Gottlieb MG (2015) Efeito do método Pilates em fatores de risco para doenças cardiometabólicas: uma revisão sistemática. *Sci Medica*. <https://doi.org/10.15448/1980-6108.2015.1.19839>
- Kokkinos P, Myers J (2010) Exercise and physical activity: clinical outcomes and applications. *Circulation* 122:1637–1648. <https://doi.org/10.1161/CIRCULATIONAHA.110.948349>
- Leith DE, Bradley M (1976) Ventilatory muscle strength and endurance training. *J Appl Physiol* 41:508–516. <https://doi.org/10.1152/jappl.1976.41.4.508>
- Lessen D (2014) Exame de certificação em Pilates da PMA: guia de estudo. Pilates Method Alliance
- Lim HS, Yoon S (2017) The effects of Pilates exercise on cardiopulmonary function in the chronic stroke patients: a randomized controlled trials. *J Phys Ther Sci* 29:959–963. <https://doi.org/10.1589/jpts.29.959>
- Martins-Meneses DT, Antunes HKM, de Oliveira NRC, Medeiros A (2015) Mat Pilates training reduced clinical and ambulatory blood pressure in hypertensive women using antihypertensive medications. *Int J Cardiol* 179:262–268. <https://doi.org/10.1016/j.ijcard.2014.11.064>
- Mello PR, Guerra GM, Borile S et al (2012) Inspiratory muscle training reduces sympathetic nervous activity and improves inspiratory muscle weakness and quality of life in patients with chronic heart failure: a clinical trial. *J Cardiopulm Rehabil Prev* 32:255–261. <https://doi.org/10.1097/HCR.0b013e31825828da>
- Mills KT, Bundy JD, Kelly TN et al (2016) Global disparities of hypertension prevalence and control: a systematic analysis of population-based studies from 90 countries. *Circulation* 134:441–450. <https://doi.org/10.1161/CIRCULATIONAHA.115.018912>
- Mills KT, Stefanescu A, He J (2020) The global epidemiology of hypertension. *Nat Rev Nephrol* 16:223–237. <https://doi.org/10.1038/s41581-019-0244-2>
- Pan American Health Organization ENLACE: data portal on noncommunicable diseases, mental health, and external causes
- Park H-Y, Jung K, Jung W-S et al (2023) Effects of online Pilates and face-to-face pilates intervention on body composition, muscle mechanical properties, cardiometabolic parameters, mental health, and physical fitness in middle-aged women with obesity. *Healthc Basel Switz* 11:2768. <https://doi.org/10.3390/healthcare11202768>
- Pereira MJ, Mendes R, Mendes RS et al (2022) Benefits of Pilates in the elderly population: a systematic review and meta-analysis. *Eur J Investig Health Psychol Educ* 12:236–268. <https://doi.org/10.3390/ejihpe12030018>
- Pilates JH, Miller WJ (2009) *A obra completa de Joseph Pilates. Sua saúde e o retorno à vida pela contrologia*. Phorte Editora
- Pilates JH A obra completa de Joseph Pilates: sua saúde e o retorno à vida pela Contrologia
- Pinto Souza AC, da Silva BL, da Nascimento Cruz S, C, et al (2021) Pilates method on pulmonary function and range of motion after

- coronary artery bypass grafting: a clinical trial. *J Bodyw Mov Ther* 28:552–556. <https://doi.org/10.1016/j.jbmt.2021.09.006>
- Pires KA, Rocha DS, Gotti Alves RR et al (2024) Acute effects of a pilates method session on flexibility and performance in practitioners of an extreme conditioning program: A preliminary study. *J Bodyw Mov Ther* 39:330–334. <https://doi.org/10.1016/j.jbmt.2024.03.017>
- Rahman F, Pechnik S, Gross D et al (2011) Low frequency power of heart rate variability reflects baroreflex function, not cardiac sympathetic innervation. *Clin Auton Res off J Clin Auton Res Soc* 21:133–141. <https://doi.org/10.1007/s10286-010-0098-y>
- Rethy L, Shah NS, Paparello JJ et al (2020) (2020) Trends in hypertension-related cardiovascular mortality in the united states, 2000 to 2018. *Hypertens Dallas Tex* 76:e23–e25. <https://doi.org/10.1161/HYPERTENSIONAHA.120.15153>
- Ruberti OM, Sousa AS, Viana LR et al (2021) Aerobic training prevents cardiometabolic changes triggered by myocardial infarction in ovariectomized rats. *J Cell Physiol* 236:1105–1115. <https://doi.org/10.1002/jcp.29919>
- Saco-Ledo G, Valenzuela PL, Ruiz-Hurtado G et al (2020) Exercise reduces ambulatory blood pressure in patients with hypertension: a systematic review and meta-analysis of randomized controlled trials. *J Am Heart Assoc*. <https://doi.org/10.1161/JAHA.120.018487>
- Schnabel E, Karrasch S, Schulz H et al (2011a) High blood pressure, antihypertensive medication and lung function in a general adult population. *Respir Res*. <https://doi.org/10.1186/1465-9921-12-50>
- Schnabel E, Nowak D, Brasche S et al (2011b) Association between lung function, hypertension and blood pressure medication. *Respir Med* 105:727–733. <https://doi.org/10.1016/j.rmed.2010.12.023>
- Takase M, Yamada M, Nakamura T et al (2023) Association between lung function and hypertension and home hypertension in a Japanese population: the Tohoku Medical Megabank Community-Based Cohort Study. *J Hypertens* 41:443–452. <https://doi.org/10.1097/HJH.0000000000003356>
- Tinoco-Fernández M, Jiménez-Martín M, Sánchez-Caravaca MA et al (2016) The Pilates method and cardiorespiratory adaptation to training. *Res Sports Med Print* 24:281–286. <https://doi.org/10.1080/15438627.2016.1202829>
- Tzelepis GE, Vega DL, Cohen ME et al (1994a) Pressure-flow specificity of inspiratory muscle training. *J Appl Physiol Bethesda Md* 77:795–801. <https://doi.org/10.1152/jappl.1994.77.2.795>
- Tzelepis GE, Vega DL, Cohen ME (1994b) McCool FD (1994b) Lung volume specificity of inspiratory muscle training. *J Appl Physiol* Bethesda Md 77:789–794. <https://doi.org/10.1152/jappl.1994.77.2.789>
- Valdez R (1991) A simple model-based index of abdominal adiposity. *J Clin Epidemiol* 44:955–956. [https://doi.org/10.1016/0895-4356\(91\)90059-1](https://doi.org/10.1016/0895-4356(91)90059-1)
- Valdez R, Seidell JC, Ahn YI, Weiss KM (1993) A new index of abdominal adiposity as an indicator of risk for cardiovascular disease. A cross-population study. *Int J Obes Relat Metab Disord J Int Assoc Study Obes* 17:77–82
- Vera-Saura P, Agudo-Pavón J, Velázquez-Torres DM et al (2024) The importance of mind-body in Pilates method in patients with chronic non-specific low back pain-a randomized controlled trial. *J Clin Med* 13:4731. <https://doi.org/10.3390/jcm13164731>
- Wang B, Zhou Y, Xiao L et al (2018) Association of lung function with cardiovascular risk: a cohort study. *Respir Res* 19:214. <https://doi.org/10.1186/s12931-018-0920-y>
- Wasser JG, Vasilopoulos T, Zdziarski LA, Vincent HK (2017) Exercise benefits for chronic low back pain in overweight and obese individuals. *PM R* 9:181–192. <https://doi.org/10.1016/j.pmrj.2016.06.019>
- Wasserman K (ed) (2012) Principles of exercise testing and interpretation: including pathophysiology and clinical applications, 5. ed. Wolters Kluwer, Lippincott Williams & Wilkins, Philadelphia
- Whelton PK, Carey RM, Aronow WS et al (2018) (2018) 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA Guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: executive summary: a report of the american college of cardiology/american heart association task force on clinical practice guidelines. *Hypertens Dallas Tex* 71:1269–1324. <https://doi.org/10.1161/HYP.0000000000000066>
- Woramontri C, Chaunчайyakul R, Yang A-L et al (2024) Effect of mat Pilates training on blood pressure, inflammatory, and oxidative profiles in hypertensive elderly. *Sports Basel Switz* 12:120. <https://doi.org/10.3390/sports12050120>

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