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Preliminary study: Effect of breathing exercise on hemodynamics and heart rate variability in hypertension

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ABSTRACT

Background: Various types of breathing exercises (BE) have been investigated, mostly focusing on their effects on blood pressure (BP) in hypertension (HT). However, each study has had a different BE program, and strong evidence based on a standard protocol is lacking.

Objective: The present study was designed to compare the effects of BE across different breathing patterns within the same protocol on hemodynamic and heart rate variability (HRV) parameters.

Materials and methods: The study was a randomized crossover design. 20 hypertensive patients performed deep and slow, pursed-lip, and bee-humming breathing in a random sequence of the three breathing patterns. Hemodynamics and HRV parameters were measured before and immediately after exercise.

Results: At a rate of six breaths/min for ten minutes, there was a significant effect of time on SBP ($F(1,19)=5.17$, $p<0.05$). The post hoc Bonferroni test indicated a significant reduction in SBP during pursed-lip breathing compared to baseline ($p<0.01$). In addition, no significant differences were found in DBP, HR, and HRV parameters. Moreover, pursed-lip breathing showed the largest change in mean difference with 95% CI in SBP (-3.9 (-6.6, -1.1)). While deep and slow and bee-humming breathing were (-3.5(-7.4, 0.5)) and (-0.4(-4.4, 3.6)), respectively.

Conclusion: Among the three breathing exercises, only pursed-lip breathing significantly reduced SBP after a single 10-minute session at six breaths per minute, while no significant changes were observed in DBP, HR, or HRV parameters. These findings suggest that pursed-lip breathing may be the most effective technique for short-term BP reduction in hypertensive patients under standardized conditions.

Introduction

High BP, or HT, is a condition where the force of blood against the walls of arteries is consistently too high. BP is regulated by the autonomic nervous system (ANS), a function of sympathetic and parasympathetic activity. High BP is an autonomic imbalance characterized by increased sympathetic activity, with or without reduced parasympathetic activity.[1-3] Persistent elevated BP is a significant risk factor for stroke and cardiovascular disease, which leads to morbidity and mortality.[4] Antihypertensive drugs can reduce these risks. Unfortunately, either side effects or expenses are

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associated with the medications. Non-pharmacological approaches such as lifestyle modification, including dietary control and exercise, are recommended to control BP.[3,5]

BE can be a valuable addition to the overall strategy for managing high BP. BE is a contemporized technique, and it is interesting that it reduces sympathetic activation and increases baroreflex sensitivity.[2] There are several types of BE in the physical therapy field,[6-8] and various studies have claimed the positive effects of BE on BP regulation.[9-13] Deep, slow breathing can decrease BP in hypertensive patients after individual rates and depths are set for slow, rhythmic breathing.[14] Pursed-lip breathing was also reported to significantly lower BP in HT conditions. The participants counted two and four during inspiration and expiration, respectively. This technique involves either baroreflex or mindfulness relief.[15] We were also interested in one of the popular yoga breathing techniques in this study. Four to six breaths per minute (breaths/min) of bee-humming breathing showed positive effect in hypertensive patients and shifted the ANS toward a parasympathetic tone. The possible mechanism involves the baroreceptor and vibration, which enhance parasympathetic activation.[16] However, the standard time duration and rate of the BE are inconsistent.

Recent literature on deep and slow breathing suggests a breathing rate of less than 10 or 6 breaths/min for 10 minutes in a single session.[11] We also want to know whether this protocol is as effective as BE. In addition, the literature on the short-term effects of BE on BP and HRV should be expanded. Therefore, this study aims to compare the effect of deep and slow, pursed-lip and bee-humming breathing at a similar rate and duration (six breaths/min for ten minutes) on hemodynamic parameters, including BP and HR. Moreover, HRV parameters were rarely observed, as HRV is a physiological measure of variability between heartbeats and reflects ANS function in hypertensive patients.[1,17,18]

Materials and methods

Study design

The study was a randomized crossover design, randomizing the breathing pattern sequence. Participant recruitment began on 3rd December 2022 and concluded on 7th May 2023. The study has been executed in accordance with the Belmont Report 1979, the Declaration of Helsinki 2013, and the Council for International Organizations of Medical Sciences (CIOM) 2016 for human experiments. The committee approved the protocol and methodology. Previous studies have not reported any adverse effects related to the breathing patterns. The exercise session began after the participants provided informed consent (COA No.216/65).

Patient population

Both men and women aged 40-59 years old were eligible for enrollment in the study.[19] Other inclusion criteria were the essential hypertensive patients who received anti-hypertensive medications. The participants were willing to participate in the protocol. If the participants were unable to perform BE, they were excluded. Other exclusion criteria included smoking, secondary HT, chronic lung disease (asthma, chronic obstructive lung disease, or emphysema), and menopausal syndrome.

Experimental protocol

After meeting the inclusion and exclusion criteria and providing informed consent, participants were instructed to have at least six hours of adequate sleep and to refrain from alcohol, caffeinated beverages, and spicy foods for at least six hours prior to their appointment. They were also asked to take their antihypertensive medications as usual and to wear comfortable clothing on the day of the experiment.

Initially, the participants were assessed for general characteristics and health status. Subsequently, the participants were asked to firmly tie the chest strap (Polar H10) around their chest. The Polar application (HRV logger) was paired to a smartphone via Bluetooth. Then, the participants were asked to sit in a comfortable position (head, neck, shoulders, and hands relaxed). Next, the automatic sphygmomanometer was placed on the upper arm. Finally, the researcher taught each participant the breathing pattern. To ensure that all participants deeply inhale, slow vital capacity (SVC) was monitored during the BE session using a spirometer.

After 30 minutes of quietly sitting, an automatic sphygmomanometer measured the baseline hemodynamic parameters. The HRV parameters were obtained from the Polar logger application. Then, the participants were asked to randomly perform three BE patterns: deep and slow breathing, pursed-lip breathing, and bee-humming breathing, accompanied by a video guide. Then, post-test measurements were obtained. Between each breathing pattern, the participants rested for 30 minutes as a washout period between intervention before starting the next BE (Figure 1).

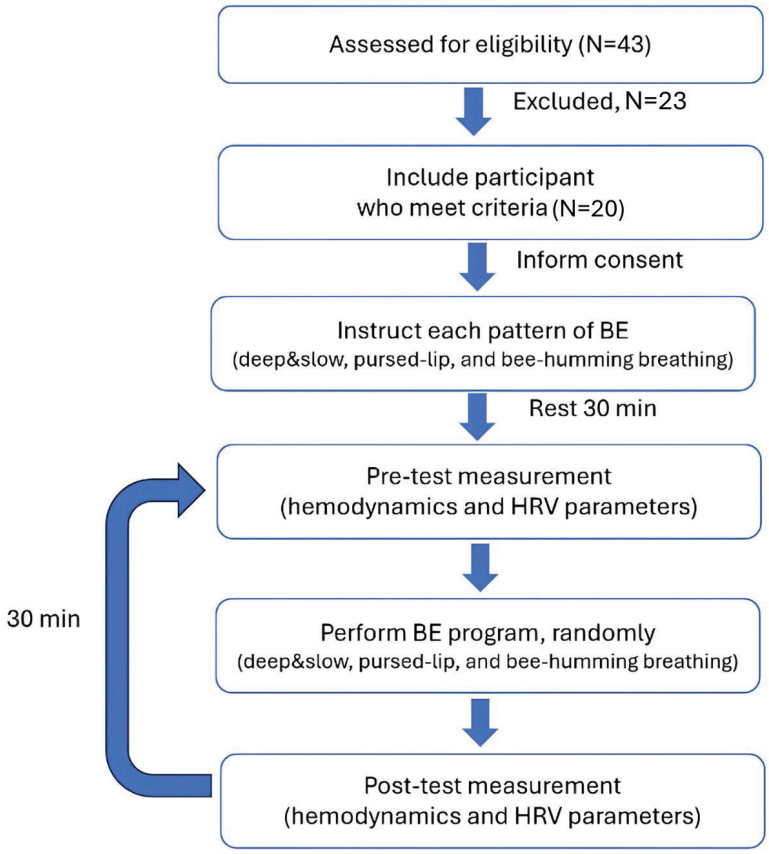


Figure 1. *Flow diagram of the experiment protocol.*

Interventions

Deep and slow breathing

The participant inhaled deeply and slowly through both nostrils for four seconds. Then, exhaled through both nostrils for six seconds. After 1 minute of deep, slow breathing, breathing control was performed at 12 breaths/min by breathing through both nostrils (inhale:exhale, 2:3), with the hand placed on the abdomen to feel the movement. This cycle was repeated for ten minutes (Figure 2A).

Pursed-lip breathing[15]

The participant inhaled deeply and slowly through both nostrils for four seconds and exhaled through the mouth while making an "O shape" with the lips for six seconds. After one minute of pursed-lip breathing, a minute of breathing control was performed. This cycle was repeated for ten minutes (Figure 2B).

Bee-humming breathing[16]

The participant inhaled through both nostrils for four seconds, followed by exhalation and the production of a humming "bee" sound ("MMMM") for six seconds. After one minute of bee-humming breathing, a minute of breathing control was performed. This cycle was repeated for ten minutes (Figure 2C). A beep sound from the video guide was used to help the patient control their breathing rate at the end of the session.

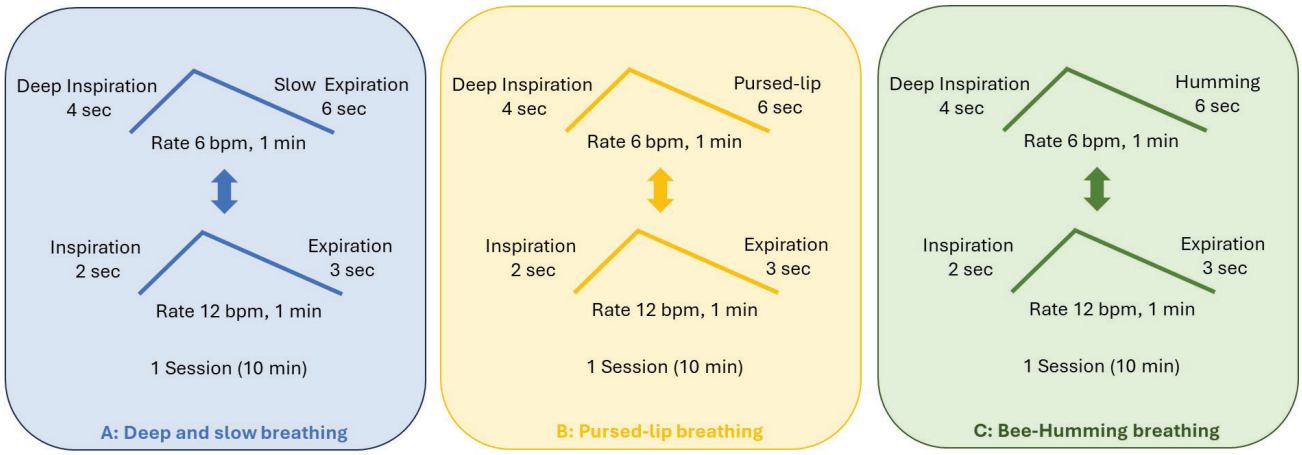


Figure 2. *BE protocol. A: deep and slow breathing, B: pursed-lip breathing, C: bee-humming breathing.*

Statistical analysis

The study outcomes were the percentage of sex, the number of antihypertensive drugs, the type of antihypertensive drugs, and other diseases. Besides, the mean±SEM of age, weight, height, body mass index (BMI), BP, HR, year since diagnosis, and HRV parameters were reported, as the SEM reflects the precision of the estimated mean and indicates how accurately the sample mean represents the population mean. Data analyses were performed using the statistical package (version 29.0; SPSS Inc, Chicago, IL). Descriptive statistics were computed to describe the sample. A Shapiro-Wilk test was conducted to ensure the distributions of the study variables. To assess whether hemodynamic or HRV parameters were modulated following the BE session, a two-way repeated-measures ANOVA was employed for parametric data, whereas nonparametric data were analyzed using the Friedman test. A p-value<0.05 was considered statistically significant. Based on the mean and SD from the previous study, the G*Power calculation indicated a minimum sample size of 20 participants.

Results

A total of 43 hypertensive patients were screened for the study. 20 fulfilled the eligibility criteria. They were instructed in three breathing patterns: deep and slow, pursed-lip, and bee-humming. The study design was a randomized crossover. Participants performed 10 minutes of BE, rested for half an hour, then repeated the process for all breathing patterns. The order of breathing patterns was randomly allocated to participants. The hemodynamics and HRV parameters were collected at the end of the exercise session. No participants were excluded during the protocol.

Descriptive data

Table 1 presents the general characteristics of the 20 hypertensive participants. The sample included equal numbers of men and women, with a mean age of 48.1±1.3 years and a mean BMI of 26.1±0.9 kg/m^2. Most participants (80%) were prescribed a single antihypertensive drug, predominantly calcium channel blockers (62.5%). BP at baseline was well-controlled, with a mean SBP of 133.9±3.6 mmHg and DBP of 87.6±2.5 mmHg. Two participants were accompanied by HT with hyperlipidemia, and one participant with diabetes mellitus (DM).

Table 1. General characteristics.

Characteristics	Mean±SEM	N (%)
Gender		
Male		10 (50.0)
Female		10 (50.0)
Age (years)	48.1±1.3	
Weight (kg)	70.3±3.1	
Height (cm)	163.7±1.5	
BMI (kg/m^2)	26.1±0.9	
SBP (mmHg)	133.9±3.6	

Table 1. General characteristics. (continue)

Characteristics	Mean±SEM	N (%)
DBP (mmHg)	87.6±2.5	
HR (bpm)	76.6±2.2	
Years since diagnosis	5.2±0.8	
Number of antihypertensive drugs		
• 1		16 (80.0)
• 2		4 (20.0)
Types of antihypertensive drugs		
• ACE Inhibitor		3 (12.5)
• Beta-blocker		1 (4.17)
• Calcium channel blocker		15 (62.5)
• Angiotensin II receptor blocker		5 (20.83)
Other diseases		
• Hyperlipidemia		2 (10.0)
• Diabetes mellitus		1 (5.0)

Note: *Value is mean±SEM or number (%), BMI: body mass index, SBP: systolic blood pressure, DBP: diastolic blood pressure, HR: heart rate, ACE Inhibitor: angiotensin converting enzyme inhibitor.*

Effect of breathing exercise on hemodynamics

An automatic BP monitor observed hemodynamics for three to four hours for all breathing patterns (Table 2). The analysis to assess the effect on SBP, DBP, and HR was performed. Two-way analysis of variance showed a significant effect of time on SBP ($F_{(1,19)}=5.17$, $p<0.05$). The post hoc Bonferroni test indicated that levels of SBP significantly decreased at the end of the 10-minute session ($p<0.01$) in pursed-lip breathing. However, there was no significant Intervention×Time interaction effect or intervention effect on SBP. No significant intervention, time, or Intervention×Time effect emerged for DBP and HR.

Table 2. Effect of breathing exercise on hemodynamics.

Parameters	Breathing technique					
	Deep and slow breathing		Pursed-lip breathing		Bee -humming breathing	
	Before	After	Before	After	Before	After
SBP (mmHg)	134.8±4.0	131.3±3.6	134.9±3.2	131.0±3.0*	133.0±4.0	132.6±3.5
DBP (mmHg)	89.5±2.9	88.2±2.8	88.1±2.6	89.0±2.6	88.1±2.6	88.8±2.8
HR (bpm)	74.7±1.8	73.9±1.8	73.3±2.3	73.3±2.0	74.6±2.0	74.8±2.0

Note: **p<0.05 indicates significant. Value is mean±SEM, SBP; systolic blood pressure, DBP; diastolic blood pressure, HR; heart rate.*

Effect of breathing exercise on HRV parameters

HRV parameters were uncertain (Table 3). The HRV parameters did not meet the assumption of normality; therefore, nonparametric tests were conducted. The test was analyzed to compare the effect of BE on HRV parameters. There was no significant difference in HRV parameters.

Table 3. Effect of breathing exercise on HRV parameters.

Parameters	Breathing technique					
	Deep and slow breathing		Pursed-lip breathing		Bee -humming breathing	
	Before	After	Before	After	Before	After
RR interval	778.59±25.03	777.92±21.00	787.67±25.09	790.68±22.06	789.66±24.82	796.83±23.88
SDNN	43.22±4.48	47.04±6.15	41.31±6.53	43.30±4.94	46.33±6.94	48.48±7.81
RMSSD	33.18±4.83	30.65±5.13	32.52±4.96	33.52±7.15	38.08±7.10	40.06±11.58
LF	0.03±0.00	0.03±0.00	0.03±0.01	0.03±0.01	0.03±0.01	0.02±0.00
HF	0.03±0.01	0.05±0.01	0.04±0.01	0.04±0.01	0.04±0.01	0.04±0.01
LF/HF ratio	1.18±0.15	0.88±0.08	1.09±0.19	0.94±0.15	1.23±0.24	0.72±0.09

Note: *Value is mean±SEM, SDNN: standard deviations of all the NN intervals, RMSSD: the root mean square of successive differences between normal heartbeats, LF: low frequency, HF: high frequency, LF/HF ratio: low frequency per high frequency ratio.*

Discussion

The study's objective aimed to compare the effect of BE (deep and slow, pursed-lip, and bee-humming breathing) on hemodynamics and HRV parameters in hypertensive patients. The time analysis found a short-term reduction in SBP, but it had no significant effect on DBP or HR. While there was no significant effect on HRV parameters.

SBP was significantly reduced at the end of the 10-minute session due to the effect of time on pursed-lip breathing. Like the previous study, which showed a significant reduction in SBP after performing ten minutes of BE.[20] Moreover, the investigation from Mitsungnern and colleagues revealed the statistical significance of SBP reduction in pursed-lip breathing exercises.[15] In addition, the investigation of our study further reported the value of the mean difference with 95% CI of SBP, including pursed-lip (-3.9(-6.6, -1.1)), deep and slow (-3.5(-7.4,0.5)), and bee-humming breathing (-0.4(-4.4, 3.6)). In this study, the mean difference in SBP reduction from pursed-lip breathing approached the minimal clinically important difference (MCID) threshold. Since SBP was the strongest predictor of stroke morbidity risk, a 4-mmHg reduction in average SBP is estimated to reduce stroke mortality by about 5.8-8.9%.[21] Therefore, although the present study found no significant intervention-by-time effect, the magnitude of reduction observed with pursed-lip breathing may still have potential clinical relevance and warrants further investigation in longer-term interventions.

Related to the study of BE on arterial baroreflex in hypertensive patients, the investigation noted that lowered BP during breathing practice is associated with increased vagal tone.[2] The following could be the mechanism of action for BE. High lung volume during inspiration expands the lung and compresses the heart chamber, thereby decreasing venous return. During expiration, the decrease in lung volume enhances venous return to the heart, resulting in an increased stroke volume. The subsequent rise in blood pressure stimulates baroreceptors, which inhibit sympathetic vasoconstrictor activity and enhance vagal innervation of the heart. Consequently, both blood pressure and heart rate decrease.[22] In addition, the pursed-lip creates back pressure, producing a small amount of positive end-expiratory pressure (PEEP), supporting the patency of the airways and alveoli in gas exchange and ventilation. Briefly, when blood gas levels are optimized, chemoreceptor activity is reduced. Since the baroreflex and chemoreflex systems interact to regulate autonomic balance, a diminished chemoreceptor drive allows baroreceptor-mediated parasympathetic activation to become more prominent. This shift leads to decreased sympathetic tone and ultimately lowers SBP.[22-24] While the postulate mechanism of bee-humming breathing reveals that the vibration of humming sound acts like an auditory stimulus that may stimulate the vagus nerve, contributing to parasympathetic tone. [16] However, the mechanism of bee-humming breathing lacks the mechanical effect of PEEP seen in pursed-lip breathing. This may explain why bee-humming breathing did not result in a significant reduction in SBP in the present study. Therefore, further research is needed.

Moreover, HRV parameters showed inconsistency across individual measures. Pursed-lip breathing appeared to increase RR interval, SDNN, and RMSSD, and slightly modulated the LF/HF ratio toward parasympathetic dominance. However, these changes were not statistically significant. According to the mechanisms discussed above regarding autonomic nervous system regulation, pursed-lip breathing may be more effective in influencing HRV responses. Although all three breathing techniques may share similar vagal stimulation effects, the scattered data observed with deep and slow breathing and bee-humming breathing limited the ability to draw definitive conclusions about autonomic modulation. Therefore, a single session may be insufficient to detect subtle autonomic changes. Future studies should include longer intervention durations and more sensitive measures to better differentiate the effects of each technique.

Limitations

For the parameters for which there was no significant finding, a previous study mentioned that ANS activity is unlikely to occur even if BE is performed in a stress state.[25] This study set up a spirometer to monitor breathing depth during BE. This discomfort may lead to stress responses. Participants may have consumed high-sodium foods, which may affect BP.[14] And the participants were properly taking anti-hypertensives that may attenuate the effect of BE.[16] Further study should aim to minimize stress during BE protocols. The biofeedback might be suitable for evaluating chest movement during BE. Food intake is recommended to control or retrain a high salt diet. The absence of a non-intervention or sham control group also limits the ability to attribute the observed effects solely to the breathing exercises. We recommend that future studies include a control group with matched time and conditions to better isolate the specific physiological effects of each breathing technique. Nevertheless, this randomized clinical trial demonstrates BE, which are easy to understand, quick to learn, and require no medical equipment. These findings underscore the need for further research to control potential confounding factors such as stress and diet, and to explore the use of biofeedback in evaluating BE.

Conclusion

This study found that among the three breathing exercises tested, only pursed-lip breathing effectively alleviates SBP after a single 10-minute session at six breaths per minute. Although deep and slow breathing and bee-humming breathing showed trends of improvement, the changes were not statistically significant. No significant effects were found in DBP, HR, or HRV parameters, possibly due to short-term intervention, antihypertensive medication use, or confounding factors such as stress or diet. Nonetheless, the modest but significant SBP reduction from pursed-lip breathing suggests it may be a simple and practical complementary approach for hypertensive patients, warranting further investigation in longer-term studies.

Ethical approval

This study was conducted in accordance with the ethical principles of the Belmont Report (1979), the Declaration of Helsinki (2013), and the Council for International Organizations of Medical Sciences (CIOMS) guidelines (2016) for research involving human participants. The study protocol and methodology were approved by the institutional ethics committee (COA No. 216/65). Written informed consent was obtained from all participants.

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Conflict of interest

The authors report no conflict of interest.

CRediT authorship contribution statement

Sirinut Chaiduang: conceptualization, methodology, investigation, data curation, formal analysis, writing: original draft and visualization, project administration; **Jirawat Wattanapanyawech**: supervision, validation, methodology, resources, writing: review and edit.

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