Regular slow-breathing exercise effects on blood pressure and breathing patterns at rest

DE Anderson, JD McNeely and BG Windham

Clinical Research Branch, Intramural Research Program, National Institute on Aging, National Institutes of Health, Baltimore, MD, USA

Previous studies reported that a device-guided slow-breathing (DGB) exercise decreases resting blood pressure (BP) in hypertensive patients. This study investigated the effects of daily practice of DGB on (a) 24-h BP and breathing patterns in the natural environment, as well as (b) BP and breathing pattern during clinic rest. Altogether, 40 participants with pre-hypertension or stage 1 hypertension were trained to decrease breathing rate through DGB or to passively attend to breathing (control, CTL) during daily 15-min sessions. The participants practiced their breathing exercise at home for 4 weeks. The DGB (but not the CTL) intervention decreased clinic resting BP, mid-day ambulatory systolic BP (in women only) and resting breathing rate, and increased resting tidal volume. However, 24-h BP level was not changed by DGB or CTL interventions, nor was overnight breathing pattern. These findings are consistent with the conclusion that a short-term, autonomic mechanism mediated the observed changes in resting BP, but provided no evidence that regular DGB affected factors involved in long-term BP regulation. Additional research will be needed to determine whether 24-h BP can be lowered by a more prolonged intervention.

Keywords: BP; breathing; tidal volume

Introduction

Several previous studies have reported that regular practice of device-guided breathing (DGB) decreases resting blood pressure (BP) of hypertensive patients. However, only three of the studies reported to date involved randomized clinical trials. Two of those did not measure BP in the natural environment, and the third was unable to confirm greater effects than in a control group. Whether the effects of DGB observed in the clinic setting extend to the natural environment is an important issue that needs to be investigated in a randomized clinical trial with 24-h BP monitoring preceding and following the DGB intervention.

A study with 24-h BP monitoring would also be relevant to the mechanism by which the enduring BP changes are generated. Performance of DGB itself is accompanied by increased cardiopulmonary stretch receptor stimulation that reduces sympathetic efferent fibre discharge, resulting in peripheral vasodilation. Thus, acute decreases in BP during DGB are mediated, at least in part, by decreases in sympathetic and increases in parasympathetic nervous system activity. Long-term changes in BP are mediated, however, not by changes in autonomic nervous system activity, but by factors that change the set point for BP.

Renal sodium regulation is sensitive to changes in breathing pattern that alter blood gas concentrations. Previous studies of DGB have found not only that tidal volume increases as breathing rate falls, but also that end tidal CO₂ (PetCO₂) decreases, apparently because of improved gas transfer associated with deeper breathing. To date, however, no studies have examined possible changes in resting breathing rate, tidal volume, minute ventilation or PetCO₂ in response to regular practice of DGB. If PetCO₂ chronically decreased in response to regular DGB, long-term effects on BP could involve alterations in blood gases and acid–base balance that alter total body sodium levels.

The effectiveness of DGB depends on the frequency of practice. For example, Elliott et al. found that a 180-min practice of DGB over an 8-week interval was a threshold for the occurrence of significant decreases in systolic BP. Although previous interventions were each of 8 weeks duration, several found that BP decreased during the first 3–4 weeks before levelling off.
This study was designed to determine whether a daily, 4-week DGB intervention decreased resting and 24-h BP in a series of subjects with pre-hypertension or stage 1 hypertension. This study also investigated whether the effects of DGB on BP are accompanied by concurrent changes in breathing patterns at rest. The effects of DGB on BP and breathing patterns were compared with those observed in a randomized control group who attended to the breathing rhythm without attempting to control its rate.

Materials and methods

Participants

In total, 102 men and women from the surrounding community responded to local advertising for a clinical trial (Clinicaltrial.gov ID # NCT00328016), and were screened over the telephone. In all, 72 respondents were invited to the National Institute on Aging Clinical Research Unit, where the purpose of the study was explained, and informed consent was obtained. A physical examination was performed, and blood and urine samples were collected to ensure that the participants were free of respiratory, cardiovascular and renal diseases. Additional exclusion criteria were diabetes or the use of tobacco, steroids, hormone-replacement therapy, angiotensin II receptor blockers, angiotensin-converting enzyme inhibitors, β-blockers or any other medications that would interfere with central nervous system activity. The protocol was approved by the Institutional Review Board of the Medstar Research Institute.

Subjects with pre-hypertension or mild hypertension were studied to eliminate the complicating effects of antihypertensive medication. A total of 30 subjects were eliminated who reported hypertensive BP over the telephone, but were found to have BP below criterion levels in the clinic. Two subjects who completed the study were removed from the data analysis because of noncompliance with intervention instructions (one in each group). The remaining 40 participants were assigned to either DGB or control (CTL) group using an open randomization procedure, and introduced to their respective breathing exercise. Table 1 shows the effectiveness of this randomization procedure in terms of the nonsignificance of differences between groups in the various pre-study measures.

Experimental design, randomization and interventions

This design had three basic phases: a period of pre-intervention monitoring, a 4-week intervention period for each of the two groups (DGB and CTL), and a period of post-intervention monitoring. Two screening sessions were scheduled to determine eligibility and establish pre-intervention baseline data, after which qualifying participants were randomized to their intervention condition. Each group practiced their respective breathing exercise daily throughout the 4-week intervention phase, after which they returned to the clinic for post-intervention monitoring.

During the pre-intervention monitoring period, each participant visited the clinic on two occasions within a 1-week interval during which breathing pattern and PetCO₂ were monitored continuously, and BP was measured every 6 min for 25 min, as described below. Candidates were declared eligible for participation if mean systolic BP of the 10 measurements during the two sessions was >130 and <160 mmHg and mean diastolic BP <100 mmHg. Between the two pre-intervention sessions, BP was recorded for 24 h in the natural environment, and breathing pattern was recorded continuously during overnight sleep.

Eligible participants were randomized to the DGB or CTL condition. The DGB condition involved the use of a commercially available device (RES-PeRATE, Lod, Israel) that guides breathing by auditory stimulation. The device includes a micro-computer that is connected to a band worn around the torso and a set of earphones. The band senses individual breathing rhythm, and calculates an initial rate to which the subject entrains breathing cycle in accord with a series of ascending and descending tones presented over the earphones. Over time, the duration of each tone increases, and breathing rate is systematically slowed, usually <10 breaths per min, and often as low as ≤6 breaths per min. Each participant was encouraged to breathe as comfortably and effortlessly as possible, while keeping the lungs moving in accord with the tones. The device contains software that enabled subsequent assessment of adherence and quantification of performance.

The control (CTL) group performed a meditative relaxation exercise. Participants were instructed to sit comfortably with eyes closed and legs and arms uncrossed, and to observe their natural breathing rhythm for 15 min, without consciously controlling it.
They were instructed to silently repeat the word ‘one’ during each exhalation interval. Daily performance at home was documented in a diary. All participants were called at home weekly to record adherence data.

Participants were instructed to practice their breathing exercise daily throughout the 4-week intervention phase. Both groups reported excellent adherence to the task instructions. Data recorded in the device showed that DGB was practiced for 27.9 ± 0.3 of the 28 days, during which mean breathing rate was <10 per min for 11.5 ± 1.0 of the 15 min. The DGB group synchronized their breathing with the tones 81.9 ± 15.3% of the time. The CTL group reported practicing on 27.9 ± 0.3 of the 28 days for an average of 17.52 ± 0.8 min per day.

During the post-intervention period, each participant returned to the clinic for a single session of 25 min of monitoring of breathing pattern, PetCO₂, and BP, as during the pre-intervention period. In addition, BP was monitored for 24 h, and overnight breathing pattern was recorded.

BP monitoring
BP was recorded in the clinic and in the natural environment using an inflatable arm cuff attached to an oscillometric device (Spacelabs, Redmond, WA, USA). During screening sessions, BP was recorded every 6 min for a total of five measurements per session. During 24-h monitoring in the natural environment, BP was recorded every 30 min for 16-h (daytime), and every 60 min for 8-h (nighttime). The BP recorder was regularly calibrated in the laboratory using sphygmomanometer.

Breathing pattern and end tidal CO₂ (PetCO₂)
Breathing rate, tidal volume and minute ventilation were recorded from an elasticized vest that summed chest and abdominal expansion on a breath-to-breath basis through inductive plethysmography (Lifeshirt, Vivometrics, Ventura, CA, USA). The vest was used for both clinic sessions and for overnight recording at home. Tidal volume was calibrated before each monitoring session by exhaling a fixed volume of air into an inflatable bag. Data from the recorder were downloaded onto a desktop computer (Dell Computer, Round Rock, TX, USA).

PetCO₂ was monitored continuously during clinic sessions using a nasal cannula connected to a respiratory gas monitor (Datex-Ohmeda, Fairfield, CT, USA). Data were recorded over successive 10-s intervals on a desktop computer (Dell Computer).

Data analysis
Independent two-tailed t-tests were used to determine whether there were any differences in biometric and physiological measurements between the two groups at baseline. The significance of the mean differences between screening sessions, the pre-intervention and post-intervention sessions was analysed for each clinic resting cardiovascular and respiratory measure through repeated measures two-way analysis of variance using Bonferroni multiple comparison tests. The significance of the differences between the pre-intervention and post-intervention measures of 24-h BP, night time BP (midnight–0800 h), ambulatory daytime BP (0800–1600 h), and evening breathing measures (1600 h–midnight) for all participants, for men and women, were also determined by repeated measures two-way analysis of variance using Bonferroni multiple comparison tests.

Results
Intervention effects on clinic resting BP
Figure 1 shows means and s.d. of resting clinic systolic BP during the two screening sessions (weeks 1 and 2) and the post-intervention session (week 6). Significant effects for time ($F_{2,38} = 6.37; P < 0.002$) and a significant interaction between group and time were observed, indicating a significantly greater decrease in systolic BP following the intervention for DGB than in the CTL group ($F_{1,38} = 3.72; P < 0.029$). The systolic BP of the DGB group was significantly lower after the intervention compared with both pre-intervention levels, which were not significantly different from each other.

Figure 1 also shows means and s.e. of resting clinic diastolic BP during the two screening sessions.
and the post-intervention session. A significant effect for time \(F_{2,38} = 9.85; \ P < 0.002\), but no interaction between time and group \(F_{1,38} = 0.22; \ P > 0.803\) was observed. Multiple comparison tests showed that resting diastolic BP of the DGB (but not CTL) group was significantly lower after the intervention than during both pre-intervention sessions.

**Intervention effects on clinic respiratory measures**

Figure 2 shows means and s.e. of breathing rate during the two screening sessions (weeks 1 and 2) and the post-intervention session (week 6). A significant interaction between time and group was observed \(F_{1,38} = 16.24; \ P < 0.001\), indicating that breathing rate of the DGB group decreased more than in the CTL group. Breathing rate of the DGB group was significantly lower after the intervention than during both pre-intervention sessions.

Figure 2 also shows means and s.e. of resting clinic tidal volume during the two screening sessions and the post-intervention session. Significant effects of time \(F_{2,38} = 6.73; \ P < 0.002\), and a significant interaction between time and group \(F_{1,38} = 7.83; \ P < 0.001\) were observed, indicating that tidal volume of the DGB group increased more than in the CTL group. Tidal volume of the DGB group was significantly larger after the intervention than during both pre-intervention sessions.

Figure 2 also shows means and s.e. of resting clinic minute ventilation during the two screening sessions and the post-intervention session. No significant effect of time \(F_{2,38} = 3.07; \ P > 0.052\), or interaction between time and group \(F_{1,38} = 0.02; \ P < 0.976\) were observed, indicating no difference between DGB and CTL groups in change in minute ventilation.

**Intervention effects on 24 h, overnight, daytime and evening BP**

Table 2 shows means and standard errors of 24 h, daytime and night time systolic and diastolic BP of the DGB and CTL groups before and after the intervention. No significant differences between groups, over time, or in the interaction of group and time were observed for 24-h systolic \(F_{1,38} = 0.12; \ P > 0.73\) or diastolic \(F_{1,38} = 0.55; \ P < 0.46\) BP.

Figure 3 shows the diurnal variation in hourly mean systolic BP preceding and following the DGB and CTL interventions, plotted separately for women and men. Figure 3 and Table 3 show that for women in the DGB group, the post-intervention daytime systolic \(t = 6.11; \ P < 0.001\) and diastolic \(t = 3.47; \ P < 0.05\) BP mean were significantly lower than the pre-intervention daytime levels. Table 3 also shows that no significant pre- to post-intervention differences were observed for overnight or evening systolic BP for women, or overnight, day-
time or evening systolic BP for men. Similarly, no significant pre- to post-intervention differences in systolic BP for women or men in the CTL group were observed in night, day, or evening segments of the 24-h BP cycle (Table 3).

**Intervention effects on overnight breathing patterns**

Table 2 also shows means and s.e. of overnight breathing rate, tidal volume, and minute ventilation for DGB and CTL groups before and after the intervention. No significant differences between groups, over time, or in the interaction between group and time were found for overnight breathing rate ($F_{1,38} = 0.48; P<0.49$), tidal volume ($F_{1,38} = 0.01; P<0.91$) or minute ventilation ($F_{1,38} = 0.21; P<0.65$).

**Discussion**

The DGB (but not the CTL) intervention decreased clinic resting BP, mid-day ambulatory systolic BP (in women only) and resting breathing rate, and increased resting tidal volume. However, 24-h BP level was not changed by the DGB or CTL interventions, nor was overnight breathing pattern.

The findings on resting BP are consistent with those in previous studies of longer duration,1–8 and support the view that the antihypertensive effects of DGB on BP operate over a pathway in which a prolonged expiratory phase of the respiratory cycle exert reflex effects that decrease peripheral vasoconstriction and increase peripheral blood flow.9 As the magnitude of BP effects of regular DGB has been
shown previously to depend on pre-intervention BP; the magnitude of the effects reported here may also reflect the borderline hypertensive condition of the sample. The findings are also consistent with the effects in a previous study that daytime BP in the workplace was accompanied by increases in perceived stress showing that acute increases in BP in the workplace with the results of a previous study with women decreases in autonomic arousal is also consistent of DGB on daytime BP in women were related to the associations of breathing pattern with BP may be with the results of other research, which suggests that female subjects, but as discussed below, is consistent or central nervous system.17

The findings in this study do not, however, support the view that regular practice of DGB has effects on mediators of long-term BP level. According to Guyton’s formulation of hypertension pathogenesis, neither changes in cardiac output or peripheral resistance that accompany changes in sympathetic nervous system activity can result in long-term changes in BP because of the ‘infinite’ ability of the kidneys to adjust blood volume up or down to maintain BP around its set point.16 The development of chronic hypertension necessarily involves changes in the set point around which BP fluctuates, the locus of which has variously been ascribed to the kidneys15 or central nervous system.17

Previous research found that sustained salt-sensitive hypertension could be generated in laboratory animals by intermittent suppression of breathing that increased pCO2 and generated a cascade of responses involving transient changes in acid–base balance and renal regulation of sodium.18 From those findings, it was speculated that regular practice of DGB might alter renal regulation of sodium and long-term BP through a respiratory mechanism that includes sustained decreases in pCO2.19 In this study, resting PetCO2 was measured before and after the DGB and CTL interventions as an index of possible changes in pCO2. In fact, a significant decrease in resting PetCO2 was observed from the first screening session to the post-intervention session in the DGB group. Positive associations between resting PetCO2 and resting BP have been observed in previous studies with women. Higher resting PetCO2 has been associated with higher resting systolic BP in women over 50 years of age,20 and especially if they scored low on trait anger.21 It has been hypothesized that high resting PetCO2 might have a permissive role in the development of sodium-sensitive form of hypertension.22

Although 24-h BP did not decrease in this study, it would be premature to conclude that regular DGB could not decrease 24-h BP under other conditions. For example, the present intervention was 4 weeks in duration, and at least two of the previous studies of DGB continued to show a progression of decreases in BP after the first 4 weeks.3,5 The adherence in this study was excellent, but 15 min per day is only a small fraction of the waking hours during which deeper, slower breathing might exert its effects. It is conceivable that an intervention that encouraged deeper breathing over a greater percentage of the day could affect the set point for BP.

In summary, the finding of no changes in 24-h BP in response to repeated practice of DGB in the context of significant changes in resting BP is potentially important because of its implications for the pathways mediating short- and long-term BP regulation. It remains to further research to clarify the

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**Table 3** Means and s.e. of systolic and diastolic blood pressure (BP) (mm Hg) for each of three 8-h intervals of the 24-h day preceding (pre) and following (post) the device-guided breathing (DGB) and control (CTL) interventions for men and women

<table>
<thead>
<tr>
<th>Group</th>
<th>Time</th>
<th>DGB</th>
<th>CTL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Night (0000–0800 h)</td>
<td>Day (0800–1600 h)</td>
<td>Evening (1600–2400 h)</td>
</tr>
<tr>
<td>Systolic BP Women</td>
<td>Pre</td>
<td>130.2 ± 1.7</td>
<td>146.8 ± 1.2</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>131.6 ± 1.0</td>
<td>141.4 ± 0.6**</td>
</tr>
<tr>
<td></td>
<td>Men Pre</td>
<td>123.7 ± 0.8</td>
<td>137.8 ± 0.8</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>128.5 ± 0.7</td>
<td>138.0 ± 1.2</td>
</tr>
<tr>
<td>Diastolic BP Women</td>
<td>Pre</td>
<td>79.9 ± 1.7</td>
<td>89.8 ± 0.5*</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>79.2 ± 0.8</td>
<td>87.2 ± 0.6</td>
</tr>
<tr>
<td></td>
<td>Men Pre</td>
<td>72.4 ± 0.5</td>
<td>84.7 ± 1.0</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>76.4 ± 0.4</td>
<td>84.8 ± 0.9</td>
</tr>
</tbody>
</table>

**P<0.001; *P<0.05.**
extent to which retraining in breathing patterns is capable of producing salutary effects on mechanisms involved in long-term BP regulation.

What is known about this topic
- Several previous studies have reported that regular practice of device-guided slow breathing exercises decrease resting blood pressure (BP) in hypertensive patients.
- Device-guided slow breathing is known to be accompanied by decreases in peripheral vasoconstriction, but whether they produce decreases in 24-h BP remains to be determined.

What this study adds
- This study shows that daily practice of device-guided slow breathing exercises decreases resting, but not 24-h BP in patients with mild hypertension.
- The decreases in resting BP are accompanied by decreases in breathing rate and increases in tidal volume at rest.
- These results raise the issue of whether the salutary effects of slow breathing exercises address the root causes of hypertension, or merely decrease the autonomic influence on BP.

Conflict of interest
The authors declare no conflict of interest.

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References