Investigating the Claims of Konstantin Buteyko, M.D., Ph.D.: The Relationship of Breath Holding Time to End Tidal CO_2 and Other Proposed Measures of Dysfunctional Breathing

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ABSTRACT

Objectives: Konstantin Buteyko, M.D., Ph.D., claimed that breath holding time (BHT) can be used to detect chronic hyperventilation and that BHT predicts alveolar CO_2 (Pa_{CO_2}) according to his patented mathematical formula. The Buteyko Breathing Technique (BBT) is believed to correct chronic hyperventilation as evidenced by increased BHT. In this study, we test Buteyko's claims and explore the relationship between BHT and end-tidal carbon dioxide ($ETCO_2$) as well as measures of dysfunctional breathing (DB) including the Nijmegen questionnaire, the Self Evaluation of Breathing Questionnaire, and thoracic dominant breathing pattern.

Subjects: Eighty-three (83) adults healthy or suspected of having dysfunctional breathing, 29 with abnormal spirometry readings, 54 with normal spirometry.

Outcome measures: BHT, performed according to BBT protocols, was measured along with $ETCO_2$ and other measures of DB including the Nijmegen questionnaire, and manual assessment of respiratory motion, a palpatory technique for measuring thoraco-abdominal balance during breathing. Correlations between measures of DB were made in the whole sample and also in subgroups with normal or abnormal spirometry. DB measures were compared in normal and abnormal spirometry groups.

Results: The results revealed a negative correlation between BHT and $ETCO_2$ ($r = -0.241$, $p < 0.05$), directly opposite to Buteyko's claims. BHT was significantly shorter in people with abnormal spirometry (FEV_1 or $FVC < 15\%$ below predicted), with no difference in $ETCO_2$ levels between the abnormal and normal spirometry groups. In the abnormal spirometry group, lower BHT was found to correlate with a thoracic dominant breathing pattern. ($r = -0.408$, $p < 0.028$).

Conclusions: Although BHT does not predict resting $ETCO_2$, it does correlate with breathing pattern in subjects with abnormal spirometry. It is proposed that altered breathing pattern could contribute to breathing symptoms such as dyspnea and that breathing therapies such as BBT might influence symptoms by improving the efficiency of the biomechanics of breathing.

INTRODUCTION

Dysfunctional breathing and breath holding time and the Buteyko Breathing Technique

For many years, clinicians and researchers have reported that abnormal or dysfunctional breathing (DB) influences health and patient's symptoms.[1–3] DB is not clearly defined and diagnosis is made on the basis of symptoms,[4,5] breathing pattern,[6,7] and presence of hyperventilation and hypocapnia.[1,3] Practitioners of the Buteyko Breathing Technique (BBT) use breath holding time (BHT) as a way of indicating the presence of DB and believe that length of BHT equates to extent of hyperventilation and degree of result-

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ing hypocapnia.[8] Current medical literature supports a broader definition of DB than one limited to hyperventilation and hypocapnia[9,10] because DB-related symptoms and abnormal breathing patterns can exist even when carbon dioxide levels are normal.[11,12]

Recent discussions on DB are beginning to consider the impact of nonbiochemical aspects of respiration[9,13,14] such as efficiency of breathing pattern. The work of breathing is most efficient when coordinated contribution from the diaphragm, abdominal muscles, and rib cage muscles results in balanced motion between the upper rib cage and the lower rib cage and abdomen.[15] Uneven distribution of chest-wall motion with dominance of upper rib cage or thoracic motion may be due to normal and transient situations such as emotional arousal or increased respiratory effort and load as well as to abnormalities of lung function.[16,17] Unevenness of motion of the chest wall where the upper rib cage movement dominates and lower rib cage expansion is impaired can indicate biomechanically induced DB that results in hyperinflation and contributes to breathing symptoms such as dyspnea.[18,19]

BHT is an indicator of a person's ventilatory response to biochemical, biomechanical, and psychologic factors,[20–22] and it seems reasonable to suggest that abnormally shortened BHT may indicate abnormalities in respiratory control that result in DB.[23,24] The idea that BHT is a simple test of DB has been suggested by various sources, including proponents of the BBT.[25]

The BBT is a breathing therapy that is used to treat at least 99 different symptoms and conditions[26] including hypertension, diabetes, sleep apnea, anxiety, depression, insomnia, and epilepsy,[27] which practitioners claim are related to DB. Asthma is the condition most people associate with BBT, and several clinical trials have indicated that the BBT helps symptom control in asthma, along with a reduction in medication use and improved quality of life.[28–32] BBT practitioners believe that the reduction of symptoms and improved health due to the BBT[8,27] are a result of increased CO_2 levels and longer BHT;[8,27] however, studies to date do not support this.[28]

Measurement of BHT is an essential part of the BBT and is integrated into its theoretical basis as well as to how the technique is practiced. Konstantin Buteyko, M.D., Ph.D., originator of the BBT, reported that his protocol for measuring breath holding could accurately predict carbon dioxide levels and detect chronic hyperventilation in both healthy and sick individuals.[33] He patented the following formula for calculating Pco_2 from BHT: $Paco_2\% = 3.5 + 0.05 \times BHT$.[34] This formula has never been subjected to rigorous scrutiny.

In this study, we aimed to test the claims of Buteyko regarding the correlation between BHT and end-tidal CO_2 ($ETCO_2$) in the general population. We also aimed to explore the relationship between BHT and DB in this same population, by examining the correlation between BHT and thoracic-dominant breathing pattern as determined by the

Manual Assessment of Respiratory Motion (MARM), as well as the presence of symptom clusters frequently associated with DB as determined by the Nijmegen Questionnaire (NQ) and the Self-Evaluation of Breathing Questionnaire (SEBQ).

Since it has been proposed that people with asthma and chronic respiratory diseases are more likely to have DB,[4] we were interested to see if these proposed measures of DB and their relationships were influenced by lung function status.

METHODS

The Human Research Ethics Committee of Royal Melbourne Institute of Technology University, Melbourne, Victoria, Australia, approved the study.

Subjects

Subjects from the general population were recruited from general practices and complementary medicine clinics in Sydney, Australia.

The study was performed on 83 volunteers, aged 18 or over who were either healthy or suffered from mild medical conditions, which did not restrict their capacity to work or significantly affect their lifestyle. Of the 83 subjects, 29 had forced expiratory volume in the first second of expiration (FEV_1) or forced vital capacity (FVC) at least 15% lower than predicted for age, gender, and race and were classified as having abnormal spirometry.

Sample size

We chose our sample size on the basis of a power analysis, which estimated that to detect a significant correlation of 0.3 with 80% power and significance level of 0.05 would require 85 subjects.

The 83 subjects were analyzed as a whole and also divided into two groups—an abnormal spirometry group of 29 subjects and a normal spirometry group of 54 subjects, for purposes of comparison.

Breath holding protocol

The breath hold test used by BBT practitioners to calculate $Paco_2$ is generally referred to as the Control Pause (CP), although the somewhat confusing term Maximum Pause (MP) is also used. CP and MP are both measured after normal exhalation at functional residual capacity.[8,27] BBT practitioners were surveyed via the Buteyko Practitioners Support Network Web site about the precise instructions used to determine correct BHT. This survey revealed that the most common instruction for determining the CP was to hold the breath until the point of definite discomfort or the first sensation of difficulty was experienced. An alternative protocol is to hold the breath until the first involuntary respira-

tory movement (IRM). This has been described as the physiologic breaking point of breath holding.[23] Private communications with Buteyko's successor, Andrey Novolizov, M.D., and his son Vladimir Buteyko, M.D., Ph.D., confirmed that to determine the CP the breath should be held till IRM. In this study, both ways of determining BHT were tested: breath holding until first difficulty or first desire to breathe (BHT-DD) and until first involuntary motion of the respiratory muscles (BHT-IRM).

Participants were instructed to sit quietly and breathe normally. They were then asked to breathe gently in and out in time and at the end of a normal exhalation to pinch their noses and hold the breath. Measurement was done with a stopwatch that measured to 0.01 of a second. This number was rounded down to 0.1 of a second. All breath-holding procedures were repeated three times and the mean was used in calculating correlations.

End-tidal carbon dioxide measurement

End-tidal carbon dioxide ($ETCO_2$) levels were sampled with a two-pronged nasal canula, and readings were taken with a capnometer (BCI, Capnocheck, Waukesha, WI). The equipment was calibrated and checked for accuracy with a known gas mixture. $ETCO_2$, along with O_2 saturation (SPO_2), respiratory rate, and heart rate, was measured for about 25 minutes while the person filled out various questionnaires. After excluding data from the first 2 minutes to allow for the subject settling in, the average $ETCO_2$ was calculated and used in determining correlation coefficients with other variables.

Other measurements

Spirometry was performed using a laptop-based spirometer (Spirocard, QRS Diagnostics, Plymouth, MN).

Breathing questionnaires. Questionnaires used to detect the possible presence of DB symptoms included the Nijmegen questionnaire (NQ) and the SEBQ. The items on the NQ are an abbreviated list of the most common symptoms of DB, and this questionnaire has been validated as an accurate tool for identifying patients likely to suffer from DB.[5] Our version of the SEBQ is derived from an abbreviation of a questionnaire available on the Internet that claimed to be able to predict whether the responder had breathing dysfunction,[35] with emphasis on symptoms that the scientific literature suggested were common in DB.[11,36] We performed Factor Analysis of the SEBQ and found two dimensions of symptoms that we named "breathlessness" and "self-perception of breathing abnormality."

Other questionnaires

The subjects were given the Hospital Anxiety and Depression Inventory to assess anxiety and depression.

The Manual Assessment of Respiratory Motion

Clinical evaluation of breathing pattern is usually performed by observation and palpation.[37] In this study, we used a breathing pattern assessment technique called the Manual Assessment of Respiratory Motion (MARM) to assess "balance" between upper and lower chest-wall movements. The MARM has been demonstrated to have good interexaminer reliability[14] and be consistent with measures performed using Respiratory Induction Plethysmography.[38]

This palpatory technique permits the examiner to assesses the relative contribution of thoracic and diaphragmatic action during breathing and calculate a quantitative measure of thoracic dominance in breathing, which we called % rib cage motion.[39] The examiner using the MARM places their open hands over the subject's back at the region of the lower four to six ribs. The examiner's thumbs are about 1 inch from the spine and oriented vertically. The examiner's hands are spread so that the lower three fingers are oriented in a transverse direction. This hand placement makes it possible for the examiner to feel lateral and vertical motion of the rib cage and assess relative contribution from the upper rib cage and the lower rib cage/abdomen. The examiner draws a diagram with an upper line to represent extent of the upper rib cage and vertical motion and a lower line to represent extent of lower rib cage/abdomen motion. Calculations are then made for thoracic diaphragm "balance" and % rib cage motion (Fig. 1).

Statistical analysis

The data were entered into the SPSS (Chicago, IL) computer program and checked for any abnormalities or errors. This program was used to calculate all statistics. Pearson's correlation coefficient was used to test for association between the two measures of BHT, BHT-DD, BHT-IRM, and all measures of DB. Student's *t*-test was used to detect differences between means of respiratory parameters and measures of DB between normal and abnormal spirometry groups.
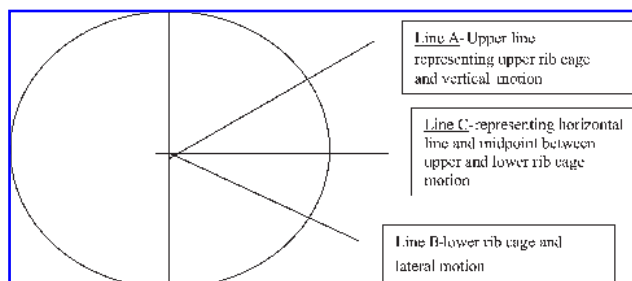

FIG. 1. Operation draws Line A to represent upper rib cage and vertical motion and Line B for lower rib cage and lateral motion. Manual assessment of respiratory motion (MARM) measures are Balance = angle AC − angle CB % Rib Cage motion = % of angle AC/angle AB.

Order of procedure

All data collection was completed within one 2-hour visit. The subjects were given the series of questionnaires to fill out while attached to the capnometer. This device was used to continuously measure $ETCO_2$, SPO_2, respiratory rate, and heart rate over approximately 25 minutes. The MARM was then performed followed by the BHT tests. BHT-DD was performed first and then BHT-IRM. The final procedure performed was spirometry, with subjects asked to perform three forced respiratory maneuvers, and the best result was used.

RESULTS

Whole group characteristics

Characteristics of subjects making up the total sample (N = 83) are shown in Table 1. In this sample, females (n = 54) outnumbered males (n = 29) and average age was 49 years. Mean values for respiratory variables such as respiratory rate, SpO_2, $ETCO_2$, and FEV_1 were all in the normal range. Scores for the Hospital Anxiety Questionnaire showed that mean scores for anxiety and depression were below the diagnostic level of 7. Similarly, mean score for the NQ was below 23, the level that indicates DB. Normal ranges for other measures of DB are not known.

Comparisons between the whole, normal, and abnormal spirometry groups

Table 2 compares values for breathing parameters and DB measures between subjects with normal and abnormal spirometry (i.e., FEV_1 or FVC less than 15% below predicted). Subjects in the abnormal spirometry group had a mean difference in % predicted FEV_1 of 17% ($p = 0.0001$). Table 2 shows that the abnormal spirometry groups had $ETCO_2$ levels 2 mm Hg higher ($p = 0.01$) and SpO_2 levels 1% lower ($p = 0.04$). They also scored 4.5 points higher on the SEBQ ($p = 0.008$). People with abnormal spiromety readings had shorter BHT for both types of breath holding (illustrated in Fig. 2) and a greater % of rib cage contribution to breathing as measured by the MARM. The difference in BHT-DD was 7.8 seconds ($p = 0.0001$) and 9 seconds for BHT-IRM ($p = 0.0001$); however, the 7% difference in MARM % rib cage was not statistically significant ($p = 0.29$).

Correlations between BHT, $ETCO_2$, and other measures of DB were performed separately on the whole group (N = 83), the abnormal spirometry group (n = 29), and the normal spirometry group (n = 54).

Correlations between BHT, $ETCO_2$, and other measures of DB in the whole group

Correlations between BHT and $ETCO_2$ and other measures of DB were performed in the whole group (N = 83).

TABLE 1. DESCRIPTIVES FOR THE WHOLE GROUP

	Whole group (n = 83)	*Normal ranges*
Males	29	—
Females	54	—
Average age (years)	49 (±14)	—
FEV_1 (% predicted)	93 (±13)	>85
Average $ETCO_2$ (mmHg)	38 (±4)	36–42
Average BHT-DD (s)	26 (±12)	—
Average BHT-IRM (s)	30 (±12)	—
Average SpO_2 (% Hb Sat)	96 (±2)	>94
RR	16 (±4)	<16
NQ	18 (±10)	<23
MARM (%RC)	73 (±27)	—
MARM Bal.	19 (±18)	—
Anxiety (HAD)	6 (±3)	<7
Depression (HAD)	3 (±3)	<7
SEBQ—Total	13 (±8)	—
SEBQ—dyspnea	4 (±3)	—
SEBQ—abnormal br	4 (±3)	—

FEV_1 (% predicted), forced expiratory volume at 1 second as a percentage of that predicted for age, race, and gender; average $ETCO_2$, average end-tidal carbon dioxide from 25 minutes' collection time; FEV_1, average BHT-DD, breath holding until first definite desire to breathe; Average BHT-IRM, average breath holding time until involuntary respiratory motion of the respiratory muscles; Average SpO_2, average percentage of hemoglobin over 25 minutes; %Hb Sat, hemoglobin saturation; RR, respiration rate (per minute); NQ; Nijmegan questionnaire; MARM Bal., manual assessment of respiratory motion (difference between total chest-wall and upper rib cage motion); MARM % RC, contribution of chest or rib cage motion to breathing; HAD, Hospital Anxiety Scale; SEBQ, Self-Evaluation of Breathing Questionnaire; SEBQ—abnormal br, SBQ-perception of breathing abnormality score.

There was a statistically significant negative correlation for $ETCO_2$ and BHT-DD ($r = -0.241$, $p = 0.028$). This correlation was strongly influenced by two cases that had very long breath holding times and very low $ETCO_2$ levels. When these two cases were excluded, no statistically significant correlations were evident (Table 3). It was decided to keep these two cases in the data because there did not appear to be any actual measurement error to justify excluding them.

As can be seen in Table 4, when the whole group was analyzed there was also a small correlation between SpO_2 and BHT-DD ($r = 0.238$, $p = 0.031$). However, there was no correlation between BHT and any of the other measures of DB.

Correlations between BHT, $ETCO_2$, and other measures of DB—abnormal spirometry group

A thoracic-dominant breathing pattern determined by the MARM measure of % rib cage motion was found to correlate with BHT in the abnormal spiromety group. In this

TABLE 2. DESCRIPTIVES AND DIFFERENCES BETWEEN THE NORMAL AND ABNORMAL SPIROMETRY GROUPS

	Normal spirometry (n = 54)	Abnormal spirometry (n = 29)	Mean difference normal & abnormal spirometry	p Values
Males	17	12		
Females	37	17		
Average age (years)	49 (±13)	48 (±14)		
FEV$_1$ (% predicted)	99 (±10)	82 (±11)	17	0.0001
Average ETCO$_2$ (mmHg)	37 (±4)	39 (±4)	2	0.01
Average BHT-DD (s)	28 (±12)	20 (±8)	7.8	0.0001
Average BHT-IRM (s)	33 (±11)	24 (±10)	9	0.0001
Average SpO$_2$ (% Hb Sat)	96 (±2)	95 (±2)	1	0.04
RR	16 (±4)	17 (±4)	1	0.79
NQ	17 (±9)	19 (±11)	2	0.35
MARM (%RC)	70 (±21)	77 (±35)	7	0.29
MARM Bal.	19 (±16)	19 (±18)	0.9	0.82
Anxiety (HAD)	6 (±3)	6 (±3)	0.2	0.79
Depression (HAD)	3 (±3)	3 (±3)	0.2	0.75
SEBQ—total	12 (±7)	16 (±8)	4.5	0.008
SEBQ—dyspnea	4 (±3)	4 (±3)	0.3	0.62
SEBQ—abnormal br	4 (±3)	5 (±4)	0.6	0.36

FEV$_1$ (% predicted), forced expiratory volume at 1 second as a percentage of that predicted for age, race, and gender; average ETCO$_2$, average end-tidal carbon dioxide from 25 minutes' collection time; FEV$_1$, average BHT-DD, breath holding until first definite desire to breathe; Average BHT-IRM, average breath holding time until involuntary respiratory motion of the respiratory muscles; Average SpO$_2$, average percentage of hemoglobin over 25 minutes; %Hb Sat, hemoglobin saturation; RR, respiration rate (per minute); NQ; Nijmegan questionnaire; MARM Bal., manual assessment of respiratory motion (difference between total chest-wall and upper rib cage motion); MARM % RC, contribution of chest or rib cage motion to breathing; HAD, Hospital Anxiety Scale; SEBQ, Self-Evaluation of Breathing Questionnaire; SEBQ—abnormal br, SBQ-perception of breathing abnormality score.

group, a significant correlation ($r = -0.408$, $p = 0.02$) existed between the MARM % rib cage motion and BHT-IRM. There was no correlation between the MARM % rib cage motion and BHT-DD ($r = 0.163$, $p = 0.398$). In this group
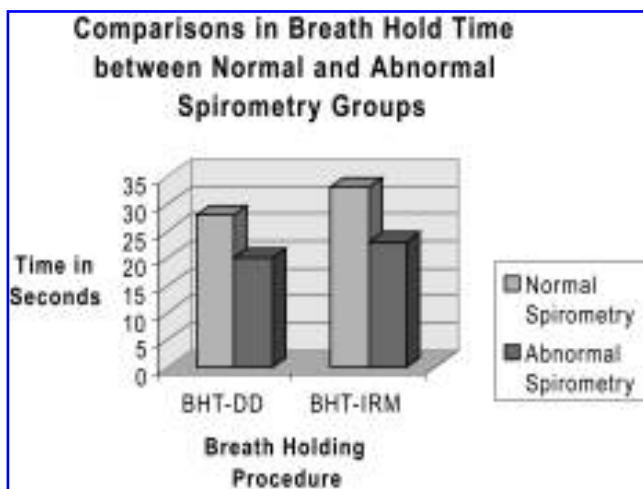

FIG. 2. Manual assessment of respiratory motion (MARM) diagram. Comparison of the two types of breath holding in people with normal spirometry and abnormal spirometry (forced expiratory volume in the first second of expiration or forced vital capacity 15% < predicted). 1: Breath holding at functional residual capacity until first feelings of definite discomfort (BHT-DD). 2: Breath holding at functional residual capacity until first involuntary motion of the respiratory muscles (BHT-IRM).

with abnormal spirometry, BHT did not correlate with lower ETCO$_2$, SPO$_2$, respiratory rate, or any other measures of DB (Table 5).

Correlations between BHT, ETCO$_2$, and other measures of DB—normal spirometry group

The only statistically significant correlations in this group were found between the NQ and BHT-IRM ($r = -0.317$, $p = 0.02$) and NQ and BHT-DD ($r = -0.315$, $p = 0.02$). There was no correlation between BHT and any of the other measures of DB (Table 6).

DISCUSSION

Relationship between BHT and ETCO$_2$

Buteyko's claim that BHT can be used to determine hypocapnia and chronic hyperventilation in the general population was not supported in this study.

In our study, a statistically significant negative correlation, opposite from the positive correlation claimed by Buteyko, was found between BHT and ETCO$_2$. The statistical significance of this negative correlation was dependent on two extreme cases who had both previously undertaken breathing training—one using yoga and the other using the BBT. The finding of long BHT with low ETCO$_2$ in these

TABLE 3. CORRELATIONS BETWEEN BREATH HOLDING TIME (BHT) AND CARBON DIOXIDE: IN THE WHOLE SAMPLE SHOWING DIFFERENCE WHEN EXCLUDING OUTLIERS

		BHT-DD all cases (n = 83)	BHT-DD excluding 2 outliers (n = 81)	BHT-IRM all cases (n = 83)	BHT-IRM excluding 2 outliers (n = 81)
P_{CO_2}	Pearson's correlation	−0.241	−0.099	−0.198	−0.040
	Sig. (2-tailed)	0.028	0.376	0.073	0.720

BHT-DD, breath holding until first difficulty or first desire to breathe; BHT-IRM, breath holding time—involuntary respiratory movement; P_{CO_2}, partial pressure of carbon dioxide.

two cases was completely opposite from what would have been predicted by Buteyko's formula but in keeping with results of at least one other study that found an inverse relationship between BHT and alveolar CO_2 tension.[40] We speculate that breath holding ability may have been increased by breathing training in these individuals and that breathing training may have led to a blunted chemoreceptor response to CO_2.

Because patients with symptomatic hyperventilation or DB are more likely to have instability of breathing rather than chronic hypocapnia,[41,42] a relationship between low BHT and intermittent hypocapnia remains a possibility.

Validity of BHT procedure

Our study found that average BHT for both types of breath holding protocols, BHT-DD and BHT-IRM, was well below the 60-second goal of Buteyko practitioners[27] but consistent with three separate studies that reported average breath holding at functional residual capacity to be 31 seconds.[20] This value is very close to the average BHT-IRM that we found to be 30 seconds. A maximal breath hold may have given a higher value closer to Buteyko's ideal; however, we found that there was a very inconsistent response when people were asked to hold their breath as long as they possibly could. This instruction sometimes led to BHT that was even shorter than BHT-DD, perhaps due to fearful anticipation of the uncomfortable sensations of prolonged

breath holding. We decided to use BHT-IRM in preference to simple instruction to "hold as long as you possibly can" as our maximal BHT. It seemed that this was a more objective or physiologic endpoint to breath holding.[43] That this was a true test of Buteyko's patent was confirmed by communications with Buteyko's Russian successors Vladimir Buteyko, M.D., Ph.D., and Marina Buteyko, M.D. (private communications 9/04/05).

Relationship between BHT and thoracic breathing pattern

The group of subjects in this study with abnormal spirometry were found to have shorter BHT than the normal spirometry group. The type of breath holding performed to first involuntary motion of respiratory muscles (i.e., BHT-IRM) was found to correspond to the thoracic breathing pattern in this group but not to $ETCO_2$.

It has been shown that in people with abnormal lung function, breathing pattern can reflect increases in respiratory center drive without causing changes in minute ventilation or carbon dioxide levels.[44] The breathing pattern shows a tendency to become more thoracic when stimulated by a variety of factors that increase respiratory center drive such as anxiety, breathing obstruction, or increased respiratory load.[16,17,45] Factors that stimulate respiratory center drive could also shorten BHT because of heightened response to sensations of dyspnea. Whether this correlation indicates any type of causal

TABLE 4. CORRELATIONS FOR BHT AND MEASURES OF DYSFUNCTIONAL BREATHING: WHOLE GROUP (N = 83)

		SpO_2	RR	NQ	MARM	SEBQ	$ETCO_2$
BHT-DD	Pearson's correlation	0.238[a]	−0.178	−0.198	−0.068	−0.174	−0.241[a]
	Sig. (2-tailed)	0.031	0.107	0.073	0.539	0.116	0.028
BHT-IRM	Pearson's correlation	0.186	−0.165	−0.185	−0.204	−0.201	−0.198
	Sig. (2-tailed)	0.093	0.137	0.095	0.064	0.069	0.073

BHT, breath holding time; BHT-DD, breath holding until first difficulty or first desire to breathe; BHT-IRM, breath holding time—involuntary respiratory movement; Sig., significance; SpO_2, oxygen saturation; RR, respiratory rate; NQ, Nijmegen questionnaire; MARM, manual assessment of respiratory motion; SEBQ, Self-Evaluation of Breathing Questionnaire; $ETCO_2$, end-tidal carbon dioxide.

[a]Statistically signficant correlations for BHT-DD with $ETCO_2$ and SpO_2.

TABLE 5. CORRELATIONS FOR BHT AND MEASURES OF DYSFUNCTIONAL BREATHING: ABNORMAL SPIROMETRY GROUP ($N = 29$)

		SpO_2	RR	NQ	$MARM$	$SEBQ$	$ETCO_2$
BHT-DD	Pearson's correlation	0.309	−0.217	0.154	0.163	0.208	−0.225
	Sig. (2-tailed)	0.103	0.258	0.424	0.398	0.278	0.241
BHT-IRM	Pearson's correlation	0.027	−0.210	0.156	−0.408[a]	0.122	−0.107
	Sig. (2-tailed)	0.891	0.275	0.418	0.028	0.528	0.580

BHT, breath holding time; BHT-DD, breath holding until first difficulty or first desire to breathe; BHT-IRM, breath holding time—involuntary respiratory movement; Sig., significance; SpO_2, oxygen saturation; RR, respiratory rate; NQ, Nijmegen questionnaire; MARM, manual assessment of respiratory motion; SEBQ, Self-Evaluation of Breathing Questionnaire; $ETCO_2$, end-tidal carbon dioxide.
[a]Statistically signficant correlations for BHT-IRM and MARM ($p < 0.05$).

relationship between thoracic breathing pattern and length of BHT needs to be elucidated by future studies.

BHT and symptom perception in asthma

Abnormal spirometry findings do not give a complete indication of lung function, and the findings of this study need to be repeated on people with diagnosed asthma. We speculate that the relationship we found in the abnormal spirometry group between short BHT and thoracic dominant breathing exists in those with asthma. Our speculation is supported by reports of other studies that reported that people with asthma and others with chronic airway obstruction exhibit profound changes in respiratory muscle function that decrease the efficiency of the biomechanics of breathing.[18,19] Increased respiratory drive and tonic contraction of inspiratory muscles, hyperinflation of the lungs, and the resulting poor diaphragm function lead to poor coordination of rib cage to diaphragm muscles and a thoracic dominant breathing pattern. The presence of hyperinflation in particular contributes to breathing symptoms such as dyspnea and respiratory sensations such as inability to take a satisfying breath.[18,46–48]

Considering that our study showed that shorter BHT correlates with a more thoracic-dominant breathing pattern, one can assume that the lengthening of BHT that is reported to occur after BBT training[8,27] could be accompanied by a more balanced and efficient breathing pattern.

A limitation of this study is that insufficient numbers of subjects in the abnormal spirometry subgroup may not have allowed us to detect significant correlations that existed in this group. Future studies should be conducted with a larger sample size to test our findings.

Another limitation of this study may have been the inclusion of subjects who had previous Buteyko or yoga training, because in this study the two subjects with previous breathing training had a disproportionately large influence on our finding of a negative correlation between BHT and CO_2.

CONCLUSIONS

Future studies are needed to clarify whether BBT training actually does result in an improved breathing pattern and whether this improved breathing pattern is a mechanism of symptom improvement in asthma.

BHT does not show a positive correlation with $ETCO_2$ as predicted by the Buteyko formula, however, BHT does correlate with the degree of thoracic dominance in breathing pattern. A thoracic-dominant breathing pattern and poor neuromechanical coupling of respiratory muscles due to hyperinflation might influence symptom perception in people with asthma. It remains to be established whether breathing pattern is responsive to breathing training and whether this

TABLE 6. CORRELATIONS FOR BHT AND MEASURES OF DYSFUNCTIONAL BREATHING: NORMAL SPIROMETRY GROUP ($N = 54$)

		SpO_2	RR	NQ	$MARM$	$SEBQ$	CO_2
BHT-DD	Pearson's correlation	0.127	−0.113	−0.317[a]	−0.174	−0.198	−0.180
	Sig. (2-tailed)	0.360	0.417	0.020	0.209	0.150	0.193
BHT-IRM	Pearson's correlation	0.138	−0.079	−0.315	−0.113	−0.206	−0.145
	Sig. (2-tailed)	0.319	0.571	0.020	0.418	0.136	0.295

BHT, breath holding time; BHT-DD, breath holding until first difficulty or first desire to breathe; BHT-IRM, breath holding time—involuntary respiratory movement; Sig., significance; SpO_2, oxygen saturation; RR, respiratory rate; NQ, Nijmegen questionnaire; MARM, manual assessment of respiratory motion; SEBQ, Self-Evaluation of Breathing Questionnaire; CO_2, carbon dioxide.
[a]Statistically signficant correlations for BHT-DD and NQ and BHT-IRM and NQ ($p < 0.05$).

is one of the therapeutic mechanisms of breathing therapies such as BBT or yoga.

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