Sonographic evaluation of diaphragmatic function during breathing control

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Declaration of Interest

The authors report no declaration of interest.

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Abstract

Objective: To investigate the effect of “breathing-control” on sonographic diaphragmatic excursion.

Method: A prospective, randomised, assessor-blinded study design involving 20 physiotherapy students; ten with knowledge of the breathing-control technique (Group-BC) and ten without (Group-CON). All participants were asked to perform a Chester-step test. Group-BC performed BC while Group-CON adopted their own breathing pattern during recovery after the step-test. Respiratory rate and sonographic parameters of the diaphragm including diaphragmatic excursion, speed of diaphragmatic contraction (slope of contraction), and inspiratory time were recorded before and after the step-test.

Results: All baseline data were similar for both groups except age. Respiratory rate at 1 min post-step test was higher in Group-CON (24.6 ± 4.9 bpm) compared to Group-BC (15.6 ± 3.8 bpm) ($p < 0.001$). Post step-test sonographic evaluation demonstrated an increase in diaphragmatic excursion with a significant time and group interaction ($F_{(4,72)} = 5.499$, $p = 0.005$). Post-hoc analysis revealed that the diaphragmatic excursion was significantly higher in Group-BC compared to Group-CON at 1st, 2nd and 3rd minute post-step test. Time and group interaction was not significant in inspiration time ($F_{(4,72)} = 2.459$, $p = 0.082$) nor the slope of contraction ($F_{(4,72)} = 0.655$, $p = 0.582$).

Conclusion: Post-exercise diaphragmatic excursion was higher in participants applying breathing-control. Non-invasive ultrasonography is able to promote objective evaluation of the relationship between breathing techniques and diaphragmatic function.

(206 words)

Key words: Breathing-control, ultrasonography, diaphragm, diaphragmatic excursion

Introduction

Shortness of breath is one of the most disabling symptoms for people with chronic respiratory illness (Pulmonary Toolkit 2009). The mainstay of symptomatic relief is bronchodilator therapy and this is often supplemented with physiotherapist-directed “breathing control”, a relaxed breathing technique aiming to reduce the sensation of dyspnea, especially during physical activities (Pulmonary Toolkit 2009). Breathing-control (BC) is also an integral component of the Active Cycle of Breathing Technique, a technique commonly adopted for secretion clearance in people with chronic respiratory conditions (Pryor & Prasad 2008, Lewis et al 2012). The BC technique usually requires a patient to assume a sitting position and place their hands anteriorly over the epigastric subcostal region, to arouse awareness of “getting air to the lower part of the chest”.

While the technique is commonly used by physiotherapists in management of patients with chronic respiratory illness (Eaton et al 2007), post-surgery (Reeve et al 2007), during weaning and after extubation from mechanical ventilation in the Intensive Care Unit (Denehy and Berney 2006), there is no evidence demonstrating that the BC technique improves diaphragmatic function.

The measurement of diaphragmatic function is however challenging. The most reliable method for evaluation of diaphragmatic function is probably the measurement of transdiaphragmatic pressure in response to magnetic stimulation of the phrenic nerve (Similowski et al 1991). However this method is invasive and requires considerable expertise and training to be performed accurately (Watson et al 2001). Non-invasive evaluation of diaphragmatic motion by M-mode ultrasonography has become popular in recent years. The validity and accuracy of ultrasound for measuring diaphragmatic motion compared to the gold standard of radiographic

imaging has been established (Noh et al 2014). The technique has been reported to be useful in monitoring of the respiratory progress of patients with diaphragmatic weakness or paralysis (Matamis et al 2013), measurement of diaphragm muscle thickness (Baldwin et al 2011; Baria et al 2014), and evaluation of diaphragmatic function in patients on mechanical ventilation (Lerolle et al 2009; Kim et al 2011) and in people with neuromuscular disease (Sarwal et al 2013). More recently, several studies have reported sonographic evaluation of diaphragmatic function in people with chronic obstructive pulmonary disease (COPD) (Paulin et al 2007; Aktürk et al 2013; Smargiassi et al 2014; Scheibe et al 2015, Rocha et al 2015). However, sonographic evaluation of the effect of the BC technique used by physiotherapists globally, on management of exertional breathlessness, has not been reported.

The aim of this pilot study is to explore the use of non-invasive sonographic technology to determine the effect of breathing-control taught by physiotherapists on diaphragmatic excursion in adults with normal health following exercise. For the current study we chose a standard exercise challenge that would increase breathing rate and frequency so as to increase diaphragmatic excursion and frequency of contraction. The intra-observer reliability of this measurement method was also determined.

METHOD

This study was approved by the ethics committee of the involved (blinded for review) university (Trial registration: HSEARS20150108003) and adopted a prospective assessor-blinded design. Prediction of sample size for this pilot study was calculated using data published by Rocha and colleagues (Rocha et al 2015). Using the mean difference and variance in diaphragmatic excursion between two groups following interventions, an effect size of 1.69 was obtained. To

power our study at 80%, with probability of type I error of .05, at least 7 subjects were required per group. To account for any potential dropouts we selected a sample size of 20 subjects (10 in each group) for our study.

Participants:

University students aged 18-22 were recruited from the Physiotherapy Department of the involved university. Ten year-3 physiotherapy students who had been taught and had practiced the breathing-control technique in class (Group-BC); and ten year-2 physiotherapy students who had not yet been taught any breathing techniques (Group-CON) were recruited.

Study design:

Exertional breathlessness was elicited using the Chester Step Test (Sykes and Roberts 2004). All participants were invited, on separate days, to attend the laboratory to perform the test. Participants in the Group-BC were instructed to use breathing control during the recovery period after the Step Test and those in the Group-CON were asked to breathe 'as usual' after the exercise intervention. Diaphragmatic movement before and immediately following the Step Test was analysed by ultrasonography conducted by a qualified sonographer who was blinded to group allocation.

Experimental procedures:

Participants were asked to arrive at the laboratory either before lunch or at least 2 hours after lunch, in comfortable clothing and footwear. Upon arrival at the laboratory, the nature of the study was explained and written consent obtained prior to commencement of data collection. All participants were screened for known cardiovascular, respiratory, neurological and musculoskeletal disease and a cardiovascular risk stratification assessment was conducted prior to data collection. Demographic data including age, height and weight were recorded.

Participants in the Group-BC were instructed to use breathing control during the recovery period after completion of the Step Test. Participants in the Group-CON were asked to breathe 'as usual' after the intervention. To ensure the briefing for different participant-groups was separate, only one subject was briefed during each measurement/recording. All breathing instructions were given in the absence of the qualified sonographer (MY, who has no knowledge of BC) which ensured the sonographer was blinded to the subject allocation. All sonographic measurements were performed by this same sonographer (MY) who has over 20 years of experience in clinical ultrasonography and ultrasonographic research, and currently an academic staff in the Department of Health Technology and Informatics at the same university.

At the commencement of the study, participants were asked to rest for 10 minutes in a sitting position while heart rate (measured and recorded by a heart rate monitor, Polar RC800CX, Polar, Finland) and respiratory rate (counted by another investigator by eye observation) were recorded. Right diaphragmatic sonography was then conducted by using a 2-4 MHz phased array probe (see below). Three consistent respiratory cycles were identified from the screen. Parameters of diaphragmatic movement from these 3 cycles were recorded and then averaged as the mean pre-exercise diaphragmatic movement pattern. Parameters recorded include diaphragmatic excursion, speed of diaphragmatic contraction (slope of contraction), and duration of the respiratory cycle.

After baseline data of diaphragmatic movement was recorded, the subject commenced the Chester Step Test (the purpose is to induce a standardized, simulated dyspnoeic condition in all participants). Test-termination criteria were: a) at completion of the test; b) heart rate reaching 80% predicted maximal heart rate ($220 - \text{age}$); or c) rate of perceived exertion reached the level of 15 (Borg Scale). Maximal oxygen consumption was predicted based on the heart rate achieved at the end of each stage. The heart rate data at the end of each stage was plotted on a prepared

graphical datasheet, maximal heart rate was predicted through extrapolation of best-fit line prediction (Sykes and Roberts 2004). Immediately following the Chester Step Test, the subject was instructed to relax and recover in a standardised long-sitting position (with back support), during which right diaphragmatic sonographic evaluation was again performed. Post-exercise respiratory rate was recorded at 1minute post-exercise with all subjects in sitting. Sonographic parameters recorded at 5 time-points (pre-step test, immediately post, 1-minute post, 2-minute post and 3-minute post-step test) were analysed.

Breathing control technique:

The breathing-control technique practiced by year 3 physiotherapy students was “reinforced” (through daily 20 min practice of the technique for 1 week prior to data collection) by an academic physiotherapist (who was specialized and experienced in cardiopulmonary research involving management of patients with chronic obstructive pulmonary disease). During the practice, the year-3 students were reminded to breathe in through the nose and out through the mouth. The academic physiotherapist guided the participants to place their dominant hand over the subcostal epigastric region, with the purpose of facilitating proprioceptive stimulation and promoting air entry into the lower lung segments beneath the participant’s hand, gradually relieving hand pressure on the skin during inspiration, and relaxing during expiration.

Sonographic evaluation:

Parameters recorded were diaphragmatic excursion, speed of diaphragmatic contraction (slope of contraction), inspiratory time and duration of the respiratory cycle. A 2-4 MHz phased array probe was placed along the right subcostal space in the anterior axillary line, and directed medially, cephalad and dorsally, using the liver as the sonographic window (Matamis et al 2012). A Philips Ultrasound Unit (HD11XE, Philips Medical System, Bothell, WA, USA) was set to

two-dimensional grey scale mode to identify the diaphragm and M-mode was then used to display diaphragmatic movement. Inspiratory and expiratory points were marked (on the ultrasound machine screen) during normal tidal breathing, the distance between these points being the displacement (excursion) of the diaphragm, and the point of inspiration to the point of expiration was recorded as the inspiratory time. The speed of diaphragmatic contraction (slope) was calculated by dividing the excursion by the inspiratory time (Figure 1).

To establish the intra-observer reliability of the ultrasound technique, measurement of the diaphragmatic movement was performed twice (without lifting of the transducer from the target area between measurements), with re-scanning by the same operator, for each participant.

Statistical analysis:

Intraclass Correlation Coefficient [$ICC_{(3,1)}$] and Standard Error Measure (SEM) were used to analyse the intra-observer reliability of the ultrasound measurements taken at baseline. Two-way repeated measures of analysis of variance (ANOVA) was used to determine the effects of breathing control on diaphragmatic function (within-subject factor: time; between-subject factor: group). Simple effect-analysis with Bonferroni adjustment was conducted when time and group interaction was found to be significant. A p value less than 0.05 was taken as statistically significant. All analyses were performed using the statistical software IBM SPSS version 20.0 (IBM Corporation, USA). All data were presented as mean $\pm$ standard deviation unless otherwise indicated.

RESULTS

Ten male and 10 female participants satisfied the inclusion and exclusion criteria and participated in the study. The intra-observer variability established by repeated baseline

measurements of diaphragmatic excursion demonstrated $ICC_{(3,1)}$ value of 0.8, standard error of measure (SEM) of 0.18; for inspiration-expiration time measurements, the values for $ICC_{(3,1)}$ and SEM were 0.83 and 0.14 respectively, and for speed of diaphragmatic contraction (Slope), the ICC and SEM values were 0.77 and 0.16 respectively (Table 1). Thus the measurement method was considered reliable. There was no statistical difference in the demographic baseline data between the two groups, except for age (Group CON was in general 1 year younger than Group BC as shown in Table 2). All participants were able to complete the step-test protocol with the heart rate and respiratory rate increased after the step-test for both groups (Table 2). There was no difference in the increase in heart rate between the two groups after the step-test challenge, however the respiratory rate at 1 minute after the step-test was greater in the control group compared to the BC group ($p<0.0001$) (Table 2).

Sonographic evaluation performed after the step-test demonstrated a similar trend of abrupt increase in diaphragmatic excursion immediately post-exercise in both groups (Figure 2), but gradual return to baseline level (Figure 3). The main effects of group ($F=17.14$, $p=0.01$) and time ($F=12.04$, $p=0.003$) were significant in diaphragmatic excursion with a significant time and group interaction effect demonstrated ($F=5.499$, $p=0.005$). Simple effect analyses with Bonferroni adjustment revealed that compared to Group-CON, the change in diaphragmatic excursion in Group-BC was significantly higher at immediately after ($F=6.47$, $p=0.02$), 1st minute ($F=12.04$, $p=0.003$), 2nd minute ($F=19.55$, $p<0.001$) and 3rd minute ($F=23.44$, $p<0.001$) post-step test.

The change in inspiratory time over time was insignificant ($F=2.48$, $p=0.051$), however a significant group effect ($F=6.03$, $p=0.024$) on inspiratory time was demonstrated, with longer

inspiratory time recorded in Group-BC compared to Group-CON. Time and group interaction ($F=2.459$, $p=0.082$), however, was not significant.

Significant main effect of time was observed in the mean slope of contraction ($F=52.3$, $p<0.001$) while no significant main effect of group ($F=0.28$, $p=0.606$) nor time and group interaction ($F=0.655$, $p=0.582$). These results suggested that the mean slope of contraction changed over time with similar trend in both groups. Table 3 displays data recorded at the 5 time-points.

DISCUSSION

Reports of diagnostic ultrasonography of diaphragmatic motion date back to the 1970s (Haber et al 1975). Although not the first choice imaging procedure for diaphragmatic imaging (Gierada et al 1998) ultrasonographic analysis of diaphragmatic movement or function in patients with COPD has entered clinical use due to its non-invasive nature, portability and accuracy. Use of ultrasonography to compare diaphragmatic excursion during diaphragmatic breathing and thoracic expansion exercise in patients after upper abdominal surgery was first reported by Blaney & Sawyer (1997). Recently, sonographic evaluation of the effect of a manual assisted breathing technique (Manual Diaphragm Release Technique (MDRT)) employed by physiotherapists was reported by Rocha's team in Brazil (Rocha et al 2015). Their study demonstrated that the MDRT was effective in improving diaphragmatic mobility in people with COPD.

The current study reports ultrasonographic evaluation of breathing control (BC), a technique employed by respiratory physiotherapists for management of shortness of breath. Although subjects who participated in this pilot study were those of normal health and not patients with COPD, this study demonstrated that after exercise-induced shortness of breath, the BC technique

not only reduced respiratory rate as expected but also significantly increased diaphragmatic excursion.

Breathing control is an important component of the Active Cycle of Breathing Technique (Lewis et al 2012), and is normal tidal breathing focusing on the lower chest in a position that encourages relaxation of the upper chest and shoulders to allow movement of the lower chest and abdomen. These positions optimise the length-tension status of the diaphragm (Dean 1985). Clinically BC is taught to patients by physiotherapists to assist in patient-management of shortness of breath (Gosselink 2004); to imitate increased respiratory stress as in people with COPD, respiratory stress was induced in our study of healthy subjects using the Chester step-test. Our subjects' heart rate increased to more than 80% of their maximal heart rate. We demonstrated that respiratory rate recovery in the BC group was much more rapid when compared to the subjects who did not practice the BC technique, as evidenced by the significant reduction of respiratory rate and lengthened inspiratory time during the application of BC.

Beyond recording of respiratory rate, technological advances have now made the assessment of diaphragmatic function using sonographic analysis more available to clinicians. Mean diaphragmatic excursion at rest was between 1.7 to 1.8 cm in our healthy subjects (Table 3); this is similar to that reported by Boussuges and colleagues (Boussuges et al 2009). After a maximal breath, the diaphragmatic excursion in Boussuges' subjects (healthy men) changed from a baseline of 1.8 to 7.5 cm. In our subject cohort, the diaphragmatic excursion immediately after the step-test was between 3-4 cm. This is less than the 7.5 cm reported by Boussuges or 6.8 cm which was more recently reported by Scheibe's group (Scheibe et al 2015) and suggests that our subjects did not produce maximal breaths following the exertional challenge.

Maximal diaphragmatic excursion measured in people with COPD was understandably much lower than healthy subjects. Such measurements in people with Stage II, III and IV COPD were reported to be 0.46, 0.37 and 0.31 cm respectively (Scheibe et al 2015). In addition, diaphragmatic excursion in people after cardiac surgery was found to be as low as 0.37 cm (Lerolle et al 2009). Ultrasonography perhaps could help to provide evidence to support the role of post-operative physiotherapy intervention in recovery of diaphragmatic excursion. The current study examined healthy participants and demonstrated greater diaphragmatic excursion following an exercise challenge when compared to normal breathing. It remains to be seen if similar results would be generated in a clinical group such as COPD patients or those post-surgery. If this was the case, then using sonography to assist in the measurement of diaphragmatic mobility may be worthwhile, particularly if it were associated with improved clinical outcomes.

Diaphragmatic mobility, as measured by sonography, was shown to be positively associated with clinical outcomes such as the 6 minute walk distance and negatively related to dyspnoea in patients with COPD (Paulin et al 2007). Paulin & colleagues also showed that decreased diaphragmatic excursion was associated with increased air-trapping and shortness of breath. Our pilot study showed the diaphragmatic mobility increased in response to exercise, but with application of BC, a greater post-exercise diaphragmatic excursion was maintained compared to the control group, suggesting more control of diaphragm function with BC. While there is still the need to demonstrate the role of BC in diaphragmatic mobility in people with COPD, this pilot study provides evidence that BC has a positive effect on the motion of the diaphragm, and its role in diaphragmatic function in the management of patients with dyspnoea warrants further investigation.

The findings of this pilot study also suggest that ultrasonography measurement is reliable (as demonstrated by our high intra-observer reliability), and that ultrasound analysis is an appropriate non-invasive and objective method of evaluation of breathing techniques clinically employed by physiotherapists. Data acquisition only takes 3-5 minutes and once the inspiratory and expiratory points of a respiratory cycle have been marked, the required parameters and variables are computed by the software intrinsic to the ultrasound unit. Our findings imply potential applications of this technique in repeated, longitudinal evaluation of the effects of exercise on diaphragmatic function in people with COPD, and the effect of physiotherapeutic intercostal muscle training on diaphragmatic function during long term mechanical ventilation.

Limitation of the study

This was only a pilot study with healthy young people as subjects, however the data demonstrate that our method of assessment of diaphragmatic function is reliable and comparable with normal respiratory data reported in the literature. Our sonographic measurements were conducted only at baseline and up to 3 minutes following the Chester-step-test and prolonged post-exercise data were not recorded. We are therefore unable to infer whether BC returns diaphragmatic activity to pre-challenge status faster than the control group. Lastly, it was beyond the scope of this current study to determine the minimal important difference in diaphragmatic excursion that is meaningful to the population with COPD. However, findings of this study suggests that the role of the breathing control technique in reduction of dynamic hyperinflation in people with COPD can be feasibly explored using ultrasonography.

CONCLUSION

Our findings showed that breathing control enhanced diaphragmatic excursion after intense exercise in normal subjects, implying a scientific rationale beyond the expected reduction of respiratory rate for a respiratory technique known clinically to be effective in the management of dyspnoea.

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Figures

- Figure 1.** Sonographic recording of tidal breathing at baseline. The + markers indicate the onset of inspiration and expiration. The excursion recorded for this subject was 1.74 cm, inspiratory time of 1.45 sec and slope of contraction 1.2 cm/s
- Figure 2.** Sonographic recording of diaphragmatic movement immediately after the step-test. A: from a subject in the Breathing Control group and B: a subject from the Control group.
- Figure 3.** Diaphragmatic excursion recorded at pre-step test and at immediately post and three consecutive minutes after step-test. * denotes a significant between-group difference with adjusted p value ($p < 0.0125$). Group BC = Breathing Control group; Group CON = Control group

Tables

- Table 1:** Reliability analysis of baseline sonographic data.
- Table 2.** Group demographic and exercise data (mean $\pm$ SD)
- Table 3:** Sonographic measurement at baseline, immediately post, 1st, 2nd and 3rd minute post-step test. Data are mean $\pm$ SD.