Feasibility of High-Intensity, Interval-Based Respiratory Muscle Training in COPD*

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Background: Specific respiratory muscle training can improve respiratory muscle function in patients with COPD, but the magnitude of improvement appears dependent on the magnitude of the training load. High training loads are difficult to achieve using conventional, constant loading techniques, but may be possible using interval-based training techniques.

Methods: To assess the feasibility of high-intensity respiratory muscle training, nine subjects with moderate-to-severe COPD (FEV1 34 ± 12% predicted [mean ± SD]) completed 8 weeks of interval-based respiratory muscle training combined with a general exercise program. This involved three 20-min sessions per week, each session comprising seven 2-min bouts of breathing against a constant inspiratory threshold load, each bout separated by 1 min of unloaded recovery. Inspiratory load was progressively incremented. Respiratory muscle strength (maximum inspiratory pressure generated against an occluded airway [PImax]) and endurance (maximum pressure generated against a progressively increasing inspiratory threshold load [Pthmax]) were measured before and immediately after the 8-week training period.

Results: By the third training session (week 1), subjects breathed against a threshold that required generation of pressures equivalent to 68 ± 5% of the pretraining PImax. By week 8, this had increased to 95 ± 12% of the pretraining PImax. On completion of training, PImax had increased by 32 ± 27% (p < 0.05), Pthmax had increased by 56 ± 33% (p < 0.05), and Pthmax/PImax had increased by 20 ± 20% (p < 0.05).

Conclusions: This study has demonstrated that high-intensity, interval-based respiratory muscle training is feasible in patients with moderate-to-severe COPD, resulting in significant improvements in respiratory muscle strength and endurance when performed three times a week for 8 weeks.

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Key words: pulmonary rehabilitation; respiratory muscle training; threshold loading

Abbreviations: FRC = functional residual capacity; ISWT = incremental shuttle walking test; PImax = maximum inspiratory pressure generated against an occluded airway; Pth = threshold pressure; Pthmax = maximum pressure generated against a progressively increasing inspiratory threshold load; RV = residual volume; 6MWD = 6-min walk distance

Respiratory muscle strength and endurance is reduced in patients with COPD. Reasons for this include an increased work of breathing due to hyper-inflation, poor nutrition, and general deconditioning.1 Standard exercise rehabilitation programs are now widely used to improve whole-body exercise capacity and quality of life, and reduce dyspnea in patients with COPD. Whether these programs also improve respiratory muscle function remains unclear, with some studies showing improvements in respiratory muscle function2–7 while others show no effect.8–13 It is notable that those studies documenting an improvement in respiratory muscle function in response to whole-body training have utilized programs with greater training frequency, duration, and/or intensity than has generally been the case.2–7 It is also notable that the magnitude of the improvement observed in these studies is less than that obtained where specific respiratory muscle training has been used.2,3,7,9,14–19
Such specific training regimens usually involve breathing at increased levels of ventilation or against external mechanical loads. Whether the resulting improvements in respiratory muscle function lead to improvements in whole-body function is unclear, as some studies show increased exercise capacity,$^{14-16,19-22}$ and others show no effect.$^{7,17,21,24}$ Consequently, current guidelines for pulmonary rehabilitation do not include respiratory muscle training among their recommendations.$^{25,26}$

It may be that the conflicting findings regarding the benefits of respiratory muscle training are a result of the use of inadequate training loads and/or imprecise tests of outcome. In the design of a training program, mode, frequency, duration, and intensity should be of a level sufficient to induce the central and peripheral adaptations in respiratory muscles that characterize improvements in peripheral skeletal muscles.$^{26,27}$ Optimal physiologic gains occur in response to high training loads,$^{26,27}$ yet most studies of respiratory muscle training have applied relatively low loads. Furthermore, many of these studies have not controlled for the potential effect of learning on their outcome measures.$^{28}$

We hypothesized that a program that adopted the principles of interval training would allow a rapid progression to relatively high respiratory muscle training loads. Interval training allows very high loads to be repeatedly achieved by separating the loading periods with recovery periods and is a well-established method of maximizing the training load to improve athletic performance.$^{26,27}$ The magnitude of training response is proportional to the duration and intensity (load) of the training stimulus.$^{27}$ To our knowledge, this principle has been applied to respiratory muscle training in only two previous studies,$^{7,16}$ with the maximum loads achieved in these studies requiring generation of pressures approximating 52% and 63% of the maximum inspiratory pressure generated against an occluded airway (PImax), respectively.

Because the magnitude of the training response increases with load, we sought to apply greater loads than had been the case in these previous protocols. Our aim was to develop an easily implemented, rapidly accomplished regimen of general applicability. To this end, we devised a program that used the same work/recovery ratio throughout, systematically increasing the training stimulus by incrementing the load. In contrast to previous studies, the loads were to be incremented between sessions to the maximum tolerable. We required the program to: (1) be performed in conjunction with a general rehabilitation program, (2) be tolerable to patients with moderate-to-severe COPD, and (3) result in training effects when performed only three times a week. Outcome measures were incorporated that would help determine the mechanisms for any improvement in respiratory muscle function. Specifically, we wished to distinguish changes in the intrinsic strength and endurance of respiratory muscles from changes in the breathing pattern adopted in response to loading, or changes in the perception of breathlessness or effort.

### Materials and Methods

#### Subjects

Subjects were recruited from outpatients with COPD scheduled to commence a pulmonary rehabilitation program. Inclusion criteria required subjects to be ≥75 years old, and to have moderate-to-severe airflow obstruction (FEV1 < 65% predicted), minimal airway reversibility, stable drug therapy, and no significant coexisting disease affecting the ability to undertake exercise. The study was approved by the Ethics Committee of Sir Charles Gairdner Hospital, and written informed consent was obtained prior to participation.

#### Study Design

Each subject was studied for a total of 11 weeks. During the first 2 weeks, measurements were obtained of resting pulmonary function, respiratory muscle function, exercise capacity (incremental cycle ergometry, 6-min walk distance [6MWD], and incremental shuttle walking test [ISWT]), and quality of life. Subjects then underwent an 8-week training program consisting of three sessions per week, each session involved participation in a general exercise program (60 min) that was immediately followed by specific respiratory muscle training (20 min). Immediately following the 8-week program, subjects were retested over a 1-week period for resting pulmonary function, respiratory muscle function, exercise capacity, and quality of life.

#### Preliminary Testing

**Resting Pulmonary Function:** Measurements were obtained of total lung capacity with a body plethysmograph (Collins; Brain-tree, MA), FVC, residual volume (RV), FEV1 (digital pneumotachograph, model 400VR; Hewlett Packard, Waltham, MA), and transfer factor for carbon monoxide (model 1182; P.K. Morgan Ltd; Gillingham, UK).

**Respiratory Muscle Endurance:** To allow for any potential learning effect, prior to the 8-week training program PImax and respiratory muscle endurance were measured on four separate occasions (≥24 h apart) using the methods detailed below. Respiratory muscle endurance was assessed using progressive inspiratory threshold loading.$^{29}$ Subjects breathed through a pneumotachograph connected in series to a modified inspiratory threshold valve, which required the development of a negative threshold pressure (Pth) before inspiratory airflow was achieved.$^{30,31}$ Seat and mouthpiece height were determined on the first testing occasion and maintained constant for all subsequent tests. No instructions were given to the subject regarding what breathing pattern to adopt. Pth was increased each minute by adding weights to the valve until the subject was no longer able to sustain the task despite strong encouragement (task failure). The magnitude of the load increment for each minute was identical for all pretraining and posttraining tests, being equivalent to approximately 10% of the PImax measured on the first testing occasion.

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During each test, breath-by-breath measurements were obtained of Pth (Microswitch; Honeywell; Freeport, IL), inspiratory flow, and tidal volume (Fleisch pneumotachograph and differential pressure transducer; Validyne Engineering; Northridge, CA). Arterial O₂ saturation by finger probe pulse oximetry (Ohmeda 3700; Ohmeda; Boulder CO) and transcutaneous PO₂ (TCM3; Radiometer; Copenhagen, Denmark) were monitored throughout the test. Inspiratory and expiratory time were derived from the pressure signal. Rib cage and abdominal motion were continuously monitored by respiratory inductance pneumograph (Respitrace; Ardsley, NY) with the transducers at the level of the nipples and umbilicus, respectively. These signals were calibrated by an involume maneuver and electronically summed to provide a measure of volume displacement. Changes in end-expiratory lung volume during the test were determined by referencing the summed pneumograph signal to measurements at functional residual capacity (FRC) and RV obtained before and after loaded breathing. End-expiratory lung volume was expressed as a percentage of expiratory reserve volume (RV, 0%; FRC, 100%). We have previously validated this method of measuring end-expiratory lung volume in healthy subjects against measurements obtained using body plethysmography.32 All data were recorded on a 12-channel direct writing polygraph (Graphitec Corporation; Yokohama, Japan).

During the final 10 s of each minute, the sensation of dyspnea and perception of effort were estimated using a 10-point Borg scale.33 Prior to beginning each study, the subject was reminded of the difference between “respiratory discomfort” and “effort required to take a breath.”34 At the end of each minute, cards showing a Borg scale for “breathlessness” and “effort” were held in front of the subject, who was asked to point to the number and descriptor that best corresponded to the sensations at the time. Respiratory Muscle Strength: Respiratory muscle strength was assessed before and immediately after each test of respiratory muscle endurance (see above) by measurement of the peak pressure developed during maximal inspiratory efforts at FRC against a closed airway (PImax).35 A constant FRC was ensured for all efforts by continuous monitoring of end-expiratory lung volume via the summed pneumograph signal. On each occasion, measurements were repeated until three were obtained within 5% of each other. The highest of these was recorded as PImax.

Incremental Cycle Ergometry: Ninety minutes prior to the fourth test of respiratory muscle endurance, each subject underwent a symptom-limited, incremental exercise test on an electronically braked bicycle ergometer (ER900; Jaeger; Hoechberg, Germany). Breath-by-breath measurements of gas exchange, breathing pattern, and ventilation were collected using an automated exercise metabolic system (Morgan Benchmark Exercise Test; PK Morgan Ltd). Following 4 min of seated rest, subjects were instructed to begin pedaling at 60 to 75 revolutions per minute. The initial workload was set at 20 W and incremented by 8 W every minute until exhaustion.

6MWD: The maximum distance walked by each subject on a 45-m level course in 6 min was measured. Each subject performed the test twice within a 30-min period, and the maximum distance was recorded.36

ISWT: The ISWT was performed using a standard protocol.37 Two tests were performed, separated by a 30-min recovery period, and maximum distance walked was recorded.

Quality of Life: The chronic respiratory disease questionnaire,38 which includes four domains (dyspnea, fatigue, emotional function, and mastery), was administered to each subject.

Training Program

General Exercise Rehabilitation: Immediately following preliminary testing, each subject participated in an 8-week pulmonary rehabilitation program involving supervised exercise three times per week for approximately 1 h each session. The training program emphasized endurance-type exercises, concentrating on the large muscle groups of the lower limbs, but also included unsupported upper-limb exercises. Exercise sessions began with 20 min of continuous walking; however, subjects experiencing severe dyspnea or marked O₂ desaturation adopted a walk-rest-walk protocol. This was followed by participation in a five-station upper-limb/lower-limb exercise circuit. Intensity was progressively increased over the 8-week training period.

Specific Respiratory Muscle Training: Immediately following each general rehabilitation session, subjects participated in a 20-min supervised program of respiratory muscle training. Each training session required subjects to breathe via a handheld inspiratory threshold valve (HealthScan Products; Cedar Grove, NJ) for 2 min, followed by a 1-min unloaded recovery period breathing off the valve. This was repeated seven times, for a total period of 14 min of loaded breathing and 6 min of recovery.

To familiarize subjects with the handheld breathing valve, a low inspiratory load (20% of the pretraining PImax) was applied during the first training session. The load was progressively increased so that following the third session, all subjects were generating inspiratory pressures equivalent to at least 70% of the pretraining PImax with each breath. No instructions were given to the subject regarding what breathing pattern to adopt. The load was further increased over the 8-week period with the aim of titrating to a level where subjects were just able to complete the final 2-min interval.

Posttraining Testing

During the week immediately following the 8-week exercise training program, measurements of resting pulmonary function, respiratory muscle function, exercise capacity, and quality of life were repeated. Respiratory muscle strength and endurance were measured twice (≥24 h apart), and incremental cycle ergometry preceded the second respiratory muscle function test by 90 min.

Statistical Analyses

One-way, repeated-measures analysis of variance was used to compare the test-to-test changes in measures of respiratory muscle function, the changes in training load from week to week, and the changes in breathing pattern, lung volume change, and perception of dyspnea and effort before and after the training period. Post hoc tests were performed using a Bonferroni correction. The effect of the training program on lung function, exercise capacity, and quality of life were assessed using paired t tests. All data are expressed as mean ± SD; p < 0.05 was considered significant.

RESULTS

Thirteen subjects were recruited into the study. Two subjects withdrew during the initial 2-week period due to exacerbation of their respiratory illness, and two subjects were excluded due to previously unrecognized heart conditions, revealed during the cycle ergometry test. Nine subjects, seven men and two women, aged 49 to 74 years (mean ± SD, 63 ± 8 years) with a FEV1 of 34 ± 12% predicted and a body mass index of 26 ± 4 completed all of the requirements of the study. In one subject, measure-
ments of respiratory muscle strength and endurance were obtained on only three occasions before training and one occasion after training.

Changes in Pulmonary Function, Exercise Capacity, and Quality of Life

Resting lung volumes, maximum expiratory flow rates, and diffusing capacity were unchanged by the 8-week program of general exercise and specific respiratory muscle training (Table 1). Exercise capacity was increased by training, as evidenced by significant increases in maximal workload achieved during cycle ergometry, in 6MWD, and in the distance walked during the ISWT. Improvements in measures of quality of life reached clinical as well as statistical significance.39

Respiratory Muscle Training Load

Subjects had been exposed to inspiratory threshold loading (weighted plunger) during preliminary testing, but were naïve to the handheld training device on entry loading (weighted plunger) during preliminary testing, statistical significance.39 measures of quality of life reached clinical as well as significant increases in maximal workload achieved during cycle ergometry, in 6MWD, and in the distance walked during the ISWT. Improvements in measures of quality of life reached clinical as well as statistical significance.39

Table 1—Changes in Lung Function, Exercise Capacity, and Quality of Life Before and After a Program of Whole-Body and Respiratory Muscle Training (n = 9)‡

<table>
<thead>
<tr>
<th>Variables</th>
<th>Before Training</th>
<th>After Training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total lung capacity, L</td>
<td>7.5 ± 1.6</td>
<td>7.4 ± 1.5</td>
</tr>
<tr>
<td>% predicted</td>
<td>123 ± 20</td>
<td>121 ± 19</td>
</tr>
<tr>
<td>FVC, L</td>
<td>3.0 ± 0.9</td>
<td>3.0 ± 0.8</td>
</tr>
<tr>
<td>% predicted</td>
<td>81 ± 23</td>
<td>81 ± 14</td>
</tr>
<tr>
<td>RV, L</td>
<td>4.4 ± 1.5</td>
<td>4.1 ± 1.2</td>
</tr>
<tr>
<td>% predicted</td>
<td>197 ± 63</td>
<td>183 ± 49</td>
</tr>
<tr>
<td>FEV1, L</td>
<td>0.93 ± 0.31</td>
<td>0.96 ± 0.24</td>
</tr>
<tr>
<td>% predicted</td>
<td>34 ± 12</td>
<td>36 ± 11</td>
</tr>
<tr>
<td>DLCO, mm/min/mmHg</td>
<td>12.1 ± 4.2</td>
<td>13.5 ± 4.9</td>
</tr>
<tr>
<td>% predicted</td>
<td>55 ± 20</td>
<td>61 ± 24</td>
</tr>
<tr>
<td>VO2peak, mL/kg/min</td>
<td>12.6 ± 4.0</td>
<td>13.6 ± 3.8</td>
</tr>
<tr>
<td>Maximum cycle workload, W</td>
<td>65 ± 17</td>
<td>73 ± 15†</td>
</tr>
<tr>
<td>6MWD, m</td>
<td>484 ± 107</td>
<td>520 ± 78†</td>
</tr>
<tr>
<td>ISWT, m</td>
<td>330 ± 108</td>
<td>370 ± 106†</td>
</tr>
<tr>
<td>Quality of life, CRDQ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dyspnea</td>
<td>19 ± 5</td>
<td>24 ± 6‡</td>
</tr>
<tr>
<td>Emotion</td>
<td>40 ± 6</td>
<td>44 ± 3†</td>
</tr>
<tr>
<td>Fatigue</td>
<td>18 ± 3</td>
<td>22 ± 3‡</td>
</tr>
<tr>
<td>Mastery</td>
<td>20 ± 5</td>
<td>25 ± 3‡</td>
</tr>
</tbody>
</table>

*Data are presented as mean ± SD. DLCO = diffusing capacity of the lung for carbon monoxide; VO2peak = peak oxygen consumption during incremental bicycle ergometry.

†p < 0.05.

‡Clinical significance.39

Changes in Respiratory Muscle Function

Over the course of the four pretraining tests of respiratory muscle function, PImax increased by 20 ± 15% (p < 0.05, n = 8) and maximum pressure generated against a progressively increasing inspiratory threshold load (Pthmax) increased by 31 ± 20% (p < 0.05, n = 8). All of the improvement occurred over the first three exposures, as PImax and Pthmax were not significantly different between test three and test four (60 ± 19 cm H2O and 62 ± 19 cm H2O, and 39 ± 14 cm H2O and 41 ± 17 cm H2O, respectively; n = 8). It was notable that the ratio of Pthmax/PImax (65 ± 11%) was unchanged over the four pretraining tests (p = 0.35, n = 8).

Immediately following the 8-week training program, PImax and Pthmax were remeasured on two separate occasions. Neither PImax, Pthmax, or Pthmax/PImax were significantly different between the two posttraining tests (80 ± 17 cm H2O and 77 ± 15 cm H2O, 61 ± 21 cm H2O and 64 ± 25 cm H2O, and 75 ± 16% and 81 ± 20%, respectively; n = 8). Consequently, the average values of tests three and four of the pretraining tests were compared with the average values of the two posttraining tests to assess the effect of the training program on session the training load was 66 ± 7% of the pretraining PImax. By the third session, the training load had increased to 68 ± 5% of the pretraining PImax. Thereafter, the training load remained > 70%, but was progressively increased so that by week 8 the training load had increased to 95 ± 12% of the pretraining PImax (Fig 1).

Figure 1. Training load progressively increased over the 8 weeks of respiratory muscle training. Each bar represents the average load (Pth generated with each breath, expressed as a percentage of the pretraining PImax) achieved during the three weekly sessions (n = 9; error bars ± SD). *p < 0.05 vs week two (week one was considered to be a familiarization period).
respiratory muscle function (Fig 2). In the subject who did not perform all tests, data from the final (third) test before training were compared with his solitary posttraining test. Following the training period, PImax had increased by 32 ± 27% (p < 0.05, n = 9) and Pthmax improved by 56 ± 33% (p < 0.05, n = 9). Pthmax/PImax increased by 20 ± 20% (p < 0.05, n = 9).

Changes in Breathing Pattern During Progressive Threshold Loading

Figures 3–5 show the pattern of breathing, changes in end-expiratory lung volume, and sensation of dyspnea and effort during progressive threshold loading before and after the 8-week training program. The breathing pattern changed in response to added inspiratory loads in all subjects. Following training, equivalent workloads were achieved with higher tidal volume and lower respiratory frequency, although minute ventilation was unchanged (Fig 3). The fall in respiratory frequency was a consequence of increased expiratory time, as inspiratory time was unchanged (Fig 4). The increased tidal volume was achieved by an increase in mean inspiratory flow. End-expiratory lung volume remained close to resting FRC throughout all studies, being unchanged by

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**Figure 2.** PImax and Pthmax before (Pre, open column) and after (Post, solid column) the 8-week training period (n = 9, error bars ± SD). *p < 0.05.

**Figure 3.** Breathing pattern during progressive threshold loading at maximum threshold load before training (Pthmax Pre, open bars), after training at a load equivalent to the pretraining Pthmax (Iso-Pth Post, hatched bars), and after training at maximum threshold load (Pthmax Post, solid bars) [n = 9, error bars ± SD]. *p < 0.05.
the 8-week training program (Fig 5). Following training, subjects perceived a load equivalent to the maximum achieved before training to require less effort, and to be associated with a decreased sensation of breathlessness (Fig 5).

**Discussion**

This study has demonstrated that an 8-week program of high-intensity, interval-based respiratory muscle training is feasible in patients with moderate-to-severe COPD. The program was performed in conjunction with a general rehabilitation program, was well tolerated by all participants, and resulted in significant improvements in respiratory muscle strength and endurance.

**Respiratory Muscle Training**

It is generally accepted that the higher the training load the greater the potential to stimulate physiologic adaptation in skeletal muscle. It is, however, difficult to maintain high constant training loads for prolonged periods, mainly because of the reliance on anaerobic energy, the accumulation of

![Diagram](http://journal.publications.chestnet.org/)
lactate, and resultant fatigue. Consequently, the training load applied in most constant load studies of the respiratory muscles has been low, ranging from 15 to 50% of PImax.\textsuperscript{15,17–19,40}

Interval training, which allows very high loads to be repeatedly achieved by separating the loading periods by recovery periods, is a well-established method of maximizing the magnitude of the training load for peripheral skeletal muscles.\textsuperscript{26,27} The recovery period allows time for partial replenishment of adenosine triphosphate and phosphocreatine energy stores; consequently, lactic acid accumulation may be less rapid and muscle fatigue decreased. Such loading paradigms have been shown to induce improvements in peripheral muscle strength as well as endurance.\textsuperscript{26,27}

To our knowledge, interval training has been applied in only two previous studies of respiratory muscle training in patients with moderate-to-severe COPD. Both of these studies utilized a handheld threshold-training device. Preusser et al\textsuperscript{16} trained 12 subjects with a similar degree of flow limitation to those in the present study (FEV\textsubscript{1} of 33% predicted) for 12 weeks. Breathing pattern was controlled, load was initiated at 52% of PImax and was increased every 4 weeks to maintain this load constant relative to the training-induced increase in PImax. The number of work intervals and recovery times were adjusted on a weekly basis. Larson et al\textsuperscript{7} trained subjects with an FEV\textsubscript{1} of 55% predicted for 16 weeks, 5 days a week for 30 min each day. The interval-training protocol adopted in this study required subjects to perform six work sets, each 5 min in duration separated by recovery periods lasting from 1 to 3 minutes. Training load was increased over the 3-month period, beginning at 31% of the pretraining PImax, reaching 63% of the postraining PImax in the last month. While the maximum loads achieved in these studies are generally higher than those using constant loading-type protocols, it is not clear whether such loads are of sufficient magnitude for optimal physiologic adaptation in respiratory muscle. Because the magnitude of the training response increases with load,\textsuperscript{27} we sought to apply greater loads, aiming to exceed 70% of PImax using a protocol that was simple (same work-recovery ratio throughout) and that allowed rapid progression to relatively high training loads over a relatively short (8 weeks) period.

In the present study, we familiarized subjects to the handheld training device by applying a very low load (20% of pretraining PImax) at the initial exposure. However, this was rapidly increased during subsequent intervals, so that by the end of the first session the training load was equivalent to 66 ± 7% of the pretraining PImax. On subsequent training days, load was systematically incremented to the maximum tolerated, the aim being to have each subject state that they believed that they were only just able to complete the final 2-min interval. At the end of the 8-week program, subjects were breathing against a load equivalent to 95 ± 12% of the pretraining PImax. It is, however, important to note that respiratory muscle strength improved over this time (see below), such that the training load at the end of the program was equivalent to 71 ± 6% of the postraining PImax, a load that exceeded that of previous protocols\textsuperscript{7,16} and that was achieved over a shorter time.

**Respiratory Muscle Strength and Endurance**

We observed a 20 ± 15% increase in PImax over four preliminary testing occasions, with a plateau in performance reached by test three. The rapidity of these changes, which occurred before training was commenced, suggests that a mechanism such as improved respiratory neuromuscular coordination was responsible for the improved PImax, rather than alterations in inherent muscle contractility. Regardless of the underlying mechanism, our data suggest that, like healthy individuals,\textsuperscript{28} subjects with COPD require a learning or familiarization period before reproducible measurements of PImax can be obtained. Failure to recognize such an effect may result in overestimation of the influence of training on any apparent improvement in respiratory muscle function following a training program.

The 8-week, interval-based training program adopted in this study resulted in an improvement in PImax of 32 ± 27%. The magnitude of this improvement is similar to previous studies of respiratory muscle training in comparable patient groups in which training load has been > 45% of PImax.\textsuperscript{2,3,8,16,18} In general, smaller improvements in PImax have been reported in studies using lower training loads\textsuperscript{15,16,19} or whole-body\textsuperscript{2–6} rather than specific respiratory muscle training, although the latter finding is equivocal (see below). It is notable that our high-intensity, interval-based training program resulted in improved respiratory muscle strength, despite not including a specific strength training component. This may be a consequence of the high loads achieved during training or to the nature of breathing against threshold loads that require that the initial part of every inspiratory effort be performed with a near-isometric contraction of the respiratory muscles until the threshold pressure is exceeded, when flow ensues.

Over four preliminary testing occasions, Pthmax increased by 31 ± 20%, with a plateau in performance reached by test three. Relative to this postlearning plateau value, Pthmax increased by
56 ± 33% with training. The magnitude of this increase is comparable to other studies using similar tests of respiratory muscle endurance in patients with COPD.2,7,8,14,40 However, it is important to note that these studies have used training programs requiring more sessions per week or a longer overall training time to achieve a comparable increase. While some of the observed improvement in endurance can be attributed to the increase in respiratory muscle strength (P1max), the finding that the ratio Pthmax/P1max increased from 67 to 81% implies that other factors also contributed.

The breathing pattern adopted in response to added threshold loads changed with training. At equivalent loads, there was a decrease in respiratory frequency and an increase in tidal volume and mean inspiratory flow following training.28 Such a strategy is an efficient way to deal with inspiratory threshold loads, where once the threshold pressure is exceeded, flow changes independently of pressure,30 and appears to have been “learned” over the course of the 8-week training period using the handheld threshold loading device. These changes in breathing pattern were accompanied by a decreased sensation of breathlessness and effort at equivalent loads.

It is possible that the improvement in respiratory muscle function following the training program was a consequence of the generalized whole-body exercise program rather than the specific respiratory muscle training program. While such an issue cannot be directly addressed in the present study, because of the absence of a control group who performed whole-body training without specific respiratory muscle training, examination of the literature suggests that such a possibility is unlikely. While several studies have shown improvements in respiratory muscle strength of between 5% and 27%.2–6 and/or endurance of between 15% and 23%.2,6,7 following whole-body exercise programs, others show no effect on either strength7–11 or endurance.3,8,9,12,13 It is notable, however, that those studies documenting an improvement in respiratory muscle function in response to whole-body training utilized training programs that were more intense than is normally the case in patients with moderate-to-severe COPD: training for up to 26 weeks,3 or between 4 and 5 days per week,3,7 or from 2 to 3 h per training session.2,4,6 It is also notable that the magnitude of the increase observed in these studies is less than that obtained when specific respiratory muscle training is applied, either in conjunction with2,3,7–9 or in isolation from7,14–19 a general exercise program. Therefore, while it is possible that whole-body training programs performed at an intensity greater than that in the present study could induce some improvements in respiratory muscle function, it unlikely that such an effect accounted for the substantial improvements in respiratory muscle function observed in our patient group.

Whether improvements in respiratory muscle function lead to improvements in whole-body function is also unclear, with some studies showing increased exercise capacity14–16,19–22 and others showing no effect.7,17,23,24 In the present study, we found significant improvements in whole-body exercise capacity and in all measures of quality of life following training. However, because respiratory muscle training was combined with generalized whole-body training, it is not possible to distinguish their respective contributions to these changes. Such an issue could only be addressed by inclusion of a control group which perform generalized training without specific respiratory muscle training. It was not the intention of this study to compare whole-body exercise and specific respiratory muscle training, but rather to investigate the feasibility of combining these two training modalities in a single rehabilitation program suitable for patients with moderate-to-severe COPD.

This study provides guidance as to the most productive means of conducting such a randomized controlled trial of the effect of respiratory muscle training on whole-body exercise capacity. It demonstrates that high-intensity, interval-based respiratory muscle training can be successfully combined with a standard general rehabilitation program, is well tolerated by patients with moderate-to-severe COPD, and results in substantial improvements in respiratory muscle strength and endurance when performed only three times a week over 8 weeks. It emphasizes the need, in performing such a trial, to recognize the presence of a learning effect in the measurement of respiratory muscle strength and endurance.

REFERENCES


