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Inspiratory muscle training in chronic airflow limitation: effect on exercise performance

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ABSTRACT: The effect of inspiratory muscle training (IMT) on exercise capacity in patients with chronic airflow limitation (CAL) has been debated. The present study was planned to further investigate the effects of IMT on exercise performance.

Twenty patients (aged 62 ± 1 yrs; forced expiratory volume in one second/forced vital capacity (FEV₁/FVC) $36 \pm 2\%$) were trained 30 min daily for 6 days a week during 10 weeks, with either 30% (Group 1) or 10% (Group 2) of peak maximal inspiratory pressure ($P_{I,max}$) as a training load. Exercise performance was evaluated by the distance walked in 6 min (6MWD) and by changes in oxygen consumption ($V'O_2$) and minute ventilation ($V'E$) during a progressive exercise test. Changes in $P_{I,max}$ and dyspnoea were also measured.

Results showed a significant increment in peak $P_{I,max}$ in both groups, whereas dyspnoea and 6MWD improved only in Group 1 ($p < 0.05$ and $p < 0.01$, respectively). No increment in maximal workload or in peak $V'O_2$ was observed in either group. Patients in Group 1, however, showed a reduction in $V'E$ and $V'O_2$ for the same exercise. A correlation between changes in $V'E$ and $V'O_2$ during a workload of 75 kpm·min⁻¹ was observed in Group 1 ($r = 0.92$; $p < 0.001$).

We conclude that inspiratory muscle training using a load of 30% peak maximal inspiratory pressure, improves dyspnoea, increases walking capacity and reduces the metabolic cost of exercise.

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It is known that exercise tolerance in patients with chronic airflow limitation (CAL) is limited by impaired ventilatory capacity, in part due to mechanical disadvantage of the inspiratory muscles. It has been proposed that inspiratory muscle training (IMT), by improving inspiratory muscle performance, may improve ventilatory capacity and could, thus, increase exercise performance in patients with CAL [1-4].

The effects of IMT on exercise performance have been assessed mainly by measuring: peak oxygen consumption ($V'O_2$); the maximal load achieved during a progressive exercise protocol; or the distance walked in 6 or 12 min, with variable results [5-11]. This could be due to factors that are known to affect the results of an IMT protocol. Changes in breathing strategy can affect the magnitude of the load during IMT with resistive devices.

Results of a recent meta-analysis demonstrate a beneficial effect on strength and endurance of the respiratory muscles only in those studies in which the load and the pattern of breathing during training are controlled [12]. Accordingly, some authors, recommend the use of feedback devices in order to control the load and duty cycle [2, 3], but this approach can make clinical application of IMT rather difficult. As an alternative, for clin-

ical application, the threshold inspiratory trainer has been proposed because it has the advantage of being flow-independent and of maintaining the same load over a wide range of inspiratory flow rates [13-15].

We hypothesized that IMT using a threshold inspiratory trainer can improve exercise performance through its positive effects on inspiratory muscles. To test this hypothesis, we studied the changes in dyspnoea score, walking capacity and in the metabolic cost of exercise, prior to and after 10 weeks of IMT in severe stable CAL patients.

We found that the training protocol used was able to relieve dyspnoea, improving performance of daily life activities, and to reduce the metabolic cost of exercise.

Subjects and methods

Twenty consecutive patients with CAL (13 males and 7 females) aged 56-76 yrs (mean \pm SE 62 ± 1 yrs), forced expiratory volume in one second/forced vital capacity (FEV₁/FVC) $36 \pm 2\%$, were trained using either 30% of peak maximal inspiratory pressure ($P_{I,max}$) (Group 1) or the minimal load of the respiratory trainer, approximately 10% of peak $P_{I,max}$ (Group 2). Table 1 shows the baseline characteristics of the subjects.

Table 1. - Baseline characteristics of patients

	Group 1 (n=10)	Group 2 (n=10)
Sex M/F	6/4	7/3
Age yrs	61±2	64±2
FEV ₁ % pred	40±4	37±4
FEV ₁ /FVC %	39±3	33±2
FVC % pred	82±5	89±7
P _{I,max} kPa	6.0±0.5	6.7±0.5
P _{a,O₂} kPa	8.8±0.3	7.9±0.3
P _{a,CO₂} kPa	5.5±0.3	5.6±0.25
6MWD m	303±38	316±31
Dyspnoea points	4.0±0.3	4.8±0.5

Values are presented as mean±SEM. M: male; F: female; FEV₁: forced expiratory volume in one second; FVC: forced vital capacity; P_{I,max}: maximal inspiratory pressure; P_{a,O₂}: arterial oxygen tension; P_{a,CO₂}: arterial carbon dioxide tension; 6MWD: 6 min walking distance.

Patients were randomly assigned for training with one of these loads in a double-blind fashion. The patients were unaware of the magnitude of the load and the investigators who performed the measurements were also unaware of the patient's training load. Training was performed at home using a threshold inspiratory trainer (HealthScan Products Inc., NJ, USA), for 30 min a day during 6 days a week for 10 weeks.

Inclusion criteria were: a) stable period of their disease; b) dyspnoea during daily life activities; c) FEV₁/FVC less than 60%; and d) absence of cardiac or any other disease that could interfere with exercise performance.

Patients were informed of the purpose of the study and had agreed to participate. The protocol was approved by the Ethics Committee at the School of Medicine, Catholic University of Chile.

Before starting IMT, patients were studied for 4 weeks (run-in period). During that period, they were evaluated on at least three occasions to obtain baseline values. Bronchodilator therapy was maintained in both groups throughout the study. Antibiotics were administered during respiratory infections. During the initial and final assessments, all patients had been free of symptoms of respiratory infection for at least 1 week.

Inspiratory training effects were assessed by measuring changes on peak P_{I,max}, dyspnoea, 6 min walking distance (6MWD), and exercise capacity using a cycle ergometer. For the latter two tests, respiratory effort was evaluated using Borg's psychophysical scale [16].

Changes in maximal respiratory pressure

Maximal inspiratory mouth pressure was measured at functional residual capacity (FRC) in a quasistatic way, according to the method proposed by BLACK and HYATT [17], using a PM45 ±200 cmH₂O Validyne differential pressure transducer (Northridge, CA, USA). The spurious contribution of orofacial muscles was avoided by a port with a 1.5 mm diameter hole in the mouthpiece. Peak values were recorded on a Hewlett Packard chart recorder (Palo Alto, CA, USA), and the highest value of at least five manoeuvres was considered for

results. In Group 1, measurements were performed once a week for adjustment of the training load with increasing P_{I,max}. Patients in Group 2 were also evaluated once a week, but the minimal load of the training device was maintained. Reported baseline results are the mean values obtained during the run-in period. The time course of the changes in P_{I,max} during the training period are presented.

Changes in dyspnoea

Dyspnoea was evaluated under basal conditions using the score of MAHLER *et al.* [18]. This score takes into consideration both functional impairment and the magnitude of the efforts and tasks that elicit dyspnoea. The effect of IMT was assessed using the transition dyspnoea index (TDI), proposed by these authors, which indicates improvement in relation to dyspnoea at baseline evaluation with positive numbers and worsening with negative numbers [18].

Changes in exercise tolerance

Exercise tolerance was evaluated: 1) recording the distance the patient could walk for 6 min (6MWD); and 2) with a progressive exercise test. Exercise testing was performed on a cycle ergometer, initially unloaded, and subsequently increasing the load by 75 kpm every 2 min. The test was stopped when patients were unable to continue because of dyspnoea or leg fatigue. During this test, cardiac frequency (f_C), arterial oxygen saturation (S_{a,O₂}), and blood pressure were monitored. Minute ventilation (V_E) and V_{O₂} were continuously recorded using a commercially available cardiopulmonary exercise system (Q-PlexI; Quinton, Seattle, WA, USA) with a low resistance Hans Rudolph valve.

Exercise performance was evaluated through the changes in V_E and V_{O₂} developed at the maximal load and at 75 kpm·min⁻¹ (the workload all patients were able to tolerate).

Patients exercised on three occasions during the run-in period. The results of the last trial were used as baseline. Reassessment was performed after 10 weeks of IMT.

The effects of training within- and between-groups were analysed using Student's t-test for paired and unpaired samples, linear regression, analysis of variance (ANOVA) for repeated measures and Student-Newman-Keuls *post hoc* test. A p-value less than 0.05 was considered to be statistically significant. Reported results correspond to the mean±SEM.

Results

Time course of maximal inspiratory pressure during the run-in and training periods

The run-in period included 4 weekly determinations of peak P_{I,max}. Mean values of the 20 patients are shown in figure 1. Although statistically significant differences

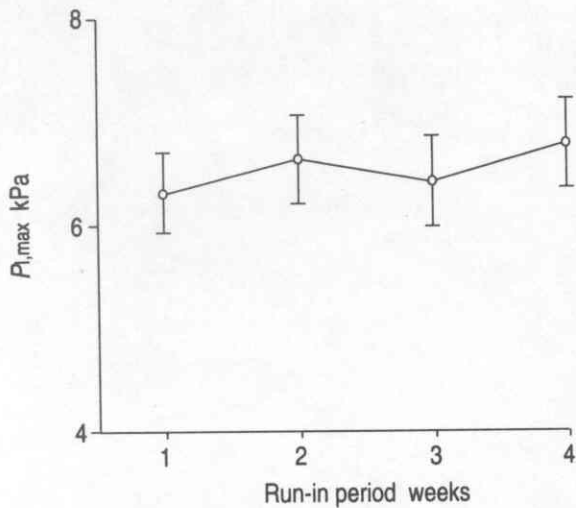


Fig. 1. — Peak maximal inspiratory pressure ($P_{1,max}$) observed during the 4 weeks of the run-in period in the 20 patients. Values are presented as mean \pm SEM.

were seen between the first and the last determination (0.44 kPa; $p=0.034$), these differences were probably not clinically important, since values obtained in the second week were higher than those obtained in the third week. In addition, the changes in $P_{1,max}$ fell within the variability of the method in our laboratory (coefficient of variation (COV) = 9.5%)

Figure 2 illustrates the time course of peak $P_{1,max}$ before and during the 10 weeks training period in both groups. A significant increase was observed in Group 1 from the second week of IMT. Peak $P_{1,max}$ increased from 6.8 ± 0.48 to 9.12 ± 0.54 kPa after 10 weeks of IMT. In Group 2, an increase of peak $P_{1,max}$ was also found with training, but differences became significant only after 5 weeks of IMT. Peak $P_{1,max}$ increased from 6.4 ± 0.47 to 7.6 ± 0.48 kPa. Although the magnitude of the increase was larger in Group 1, differences between

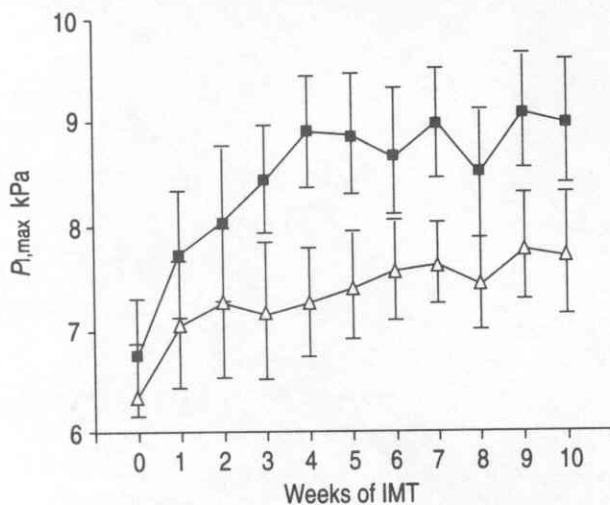


Fig. 2. — Time course of peak maximal inspiratory pressure ($P_{1,max}$) measured every week during the training period in both groups. The mean value obtained during the run-in period is also shown. A significant increment from the 2nd week was observed in Group 1. In Group 2 peak $P_{1,max}$ also increased significantly, but to a lesser degree and after the 5th week of inspiratory muscle training (IMT). —■—: Group 1; —△—: Group 2. Values are presented as mean \pm SEM.

groups at the end of the training period were not statistically significant, probably due to the large scatter in individual values (fig. 2).

Changes in dyspnoea

Both groups had a similar baseline dyspnoea score (table 1). After 10 weeks of IMT, the TDI was $+3.8\pm 0.6$ points in Group 1 and $+1.7\pm 0.6$ in Group 2 ($p=0.036$). These results imply that after 10 weeks-of IMT, patients in Group 1, on average, were able to: 1) reassume at least one activity they had abandoned because of dyspnoea; and 2) perform greater efforts and tasks than prior to IMT, at a faster speed without presenting dyspnoea. Figure 3 shows mean values for TDI after 10 weeks of IMT.

Exercise performance

Six minute walking distance. Table 2 shows mean \pm SEM values for the 6MWD and the degree of respiratory effort at the end of the test in both groups, measured with Borg's scale, before and after 10 weeks of IMT. After training, patients in Group 1 increased the walking distance ($p<0.01$) and presented less dyspnoea ($p<0.05$). No significant changes in the 6MWD or in Borg's score were observed in Group 2. Comparison between groups, after 10 weeks of training, disclosed significant differences in Borg's score ($p<0.05$), without significant differences in 6MWD, a finding that may be due to the high dispersion of values.

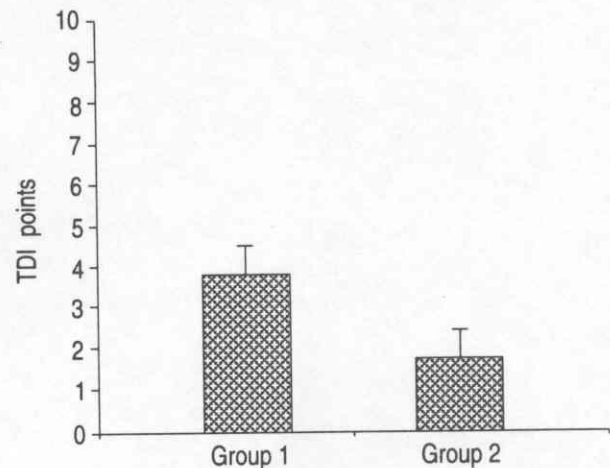


Fig. 3. — Mean values of transition dyspnoea index (TDI) after 10 weeks of inspiratory muscle training (IMT) in Group 1 and Group 2.

Table 2. — Distance walked in 6 min (6MWD) and respiratory effort measured with Borg's psychophysical scale before and after IMT

		6MWD	Borg's score
Group 1	Before IMT	303 \pm 38	6.6 \pm 0.7
	After IMT	417 \pm 34**	3.4 \pm 0.6*
Group 2	Before IMT	316 \pm 31	6.8 \pm 0.6
	After IMT	354 \pm 30	5.8 \pm 0.8

Values are presented as mean \pm SEM. IMT: inspiratory muscle training. *: $p<0.05$; **: $p<0.01$, compared to value before IMT.

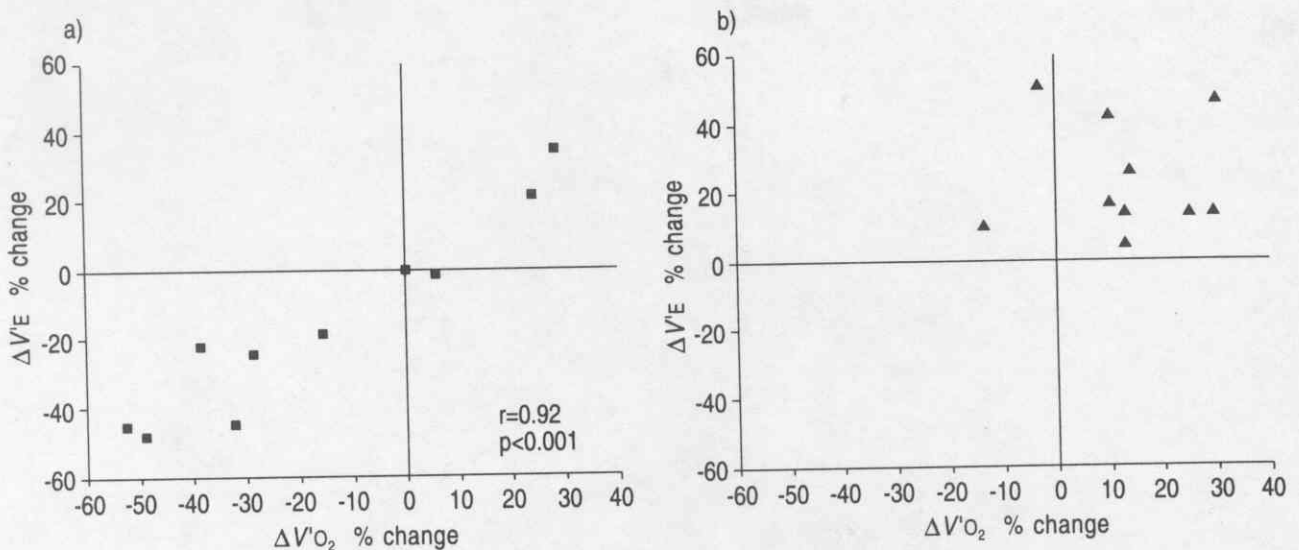


Fig. 4. — Individual percentage change in minute ventilation ($\Delta V'E$) (ordinate) and in oxygen consumption ($\Delta V'O_2$) (abscissa) before and after inspiratory muscle training (IMT): a) in Group 1; and b) in Group 2. A significant correlation was found between $\Delta V'O_2$ and $\Delta V'E$ in Group 1, with no correlation in Group 2.

Progressive cycle ergometer exercise

Maximal workload. Maximal workload did not increase in either group after IMT (189 ± 26 vs 200 ± 28 kpm·min⁻¹ in Group 1, and 187 ± 30 vs 217 ± 26 kpm·min⁻¹ in Group 2). However, a significant fall both in $V'E$, (from 33 ± 2 to 28 ± 3 L·min⁻¹) and in peak $V'O_2$ (from 815 ± 56 to 749 ± 61 mL·min⁻¹) was observed in Group 1 after training. In contrast, patients in Group 2 presented no change in $V'E$ (31 ± 4.8 vs 33 ± 4.8 L·min⁻¹) and no change in peak $V'O_2$ (782 ± 62 vs 784 ± 53 mL·min⁻¹).

Submaximal workload. Figure 4 shows individual changes in $V'E$ (ordinate), and in $V'O_2$ (abscissa) for both groups, at an exercise workload of 75 kpm·min⁻¹ after IMT. A significant correlation between changes in $V'E$ and in $V'O_2$ was found in Group 1 ($r=0.92$; $p<0.001$), whereas in Group 2 no correlation was observed.

Changes in Borg's score during maximal exercise were not statistically significant in either group.

In addition, no significant correlation between the increment in peak $P_{I,max}$ and exercise performance or dyspnoea, were observed. Changes in ventilation showed a tendency to correlate with changes in TDI ($p=0.07$).

Spirometry

In Group 1, mild, but significant increase in FVC was observed, from $2,433 \pm 173$ to $2,610 \pm 202$ mL ($p<0.001$) at 10 weeks of IMT, with no changes in FEV₁ (993 ± 93 vs $1,002 \pm 100$ mL after training). In Group 2, no changes in FVC ($2,511 \pm 182$ vs $2,422 \pm 165$ mL) or in FEV₁ (822 ± 52 vs 792 ± 52 mL) were observed with training.

Discussion

The results of the present study show that IMT using a threshold device in patients with COPD, ameliorates dyspnoea, increases the distance the patients can walk in 6 min, and reduces the metabolic cost of a submaxi-

mal exercise. These effects were observed when a target load of 30% peak $P_{I,max}$ was employed, but not when a load of 10% was used for training. These findings suggest that most of the beneficial effects of IMT can be attributed to the magnitude of the load employed. Baseline characteristics of the two groups were similar, the number of tests applied to each group were the same, and, as the study was blinded both for the operators and the patients, it is unlikely that these results could be attributed to differences in learning or coaching. For the same reasons, a training effect of repeated measurements on inspiratory muscle strength, 6MWD and progressive exercise is also unlikely. Values for exercise were those obtained in the third baseline study after the patients had learned to perform the test adequately. Although patients were not supervised while performing the training manoeuvres at home, there is no reason to believe they were not compliant, since they attended regular weekly visits to the laboratory. Furthermore, the study shows load-dependent training effects on peak $P_{I,max}$ (fig. 2).

Since controversy exists about a learning effect on $P_{I,max}$ manoeuvres, the time course of the changes in peak $P_{I,max}$ were carefully analysed both during the 4 weeks run-in period and weekly for the 10 weeks duration of the training protocol. No substantial change in $P_{I,max}$ was found during the run-in period and a significant improvement in $P_{I,max}$ was found with both loads. However, changes with a load of 30% peak $P_{I,max}$ were seen earlier and were of a larger magnitude.

It can be argued that 30% peak $P_{I,max}$ is a relatively low load for training; however, our previous experience using a threshold device [15] as well as some of the data in the literature show that this load can be high enough to attain IMT [13]. In addition, we have recently observed that this load is equivalent to 40% of the $P_{I,max}$ sustained for 1 s. As inspiratory time (t_I) employed during the training manoeuvres was over 1 s, we believe that the patient's inspiratory muscles were really trained with approximately 40% of the $P_{I,max}$ sustained for 1 s (unpublished observations).

The group trained with 10% peak $P_{I,max}$ was chosen as a control group. Although the ideal control group could have been one with zero load, we chose to use the minimum load given by the training device in order to have the study blinded, both for the patients and for the investigators. However, this minimal load of the device did have a training effect on $P_{I,max}$, without effect on the other parameters studied. BERRY *et al.* [19] recently reported an increase in $P_{I,max}$ in their control group after 12 weeks of training with a load of 15% of $P_{I,max}$.

The effect of IMT on dyspnoea was significantly greater in the group trained with the highest load. HARVER *et al.* [3] have shown a significant correlation between relief in dyspnoea and the improvement in $P_{I,max}$ measured at residual volume (RV), when the results of the trained and the results of the control subjects after IMT were analysed together. PATESSIO *et al.* [20] also found a significant correlation between the improvement in dyspnoea and the changes in $P_{I,max}$. In a previous study, we found a significant correlation between the TDI and the percentage changes in $P_{I,max}$ after 5 weeks of IMT, when we included the group trained with a low load [15]. In the present study, however, the improvement both in $P_{I,max}$ and in dyspnoea was greater in Group 1 patients, although no correlation was found in either group separately, nor when both groups were analysed together. However, to establish a correlation between changes in $P_{I,max}$ and changes in dyspnoea is difficult because of the dependence of dyspnoea on factors other than respiratory muscle strength. There is also the possibility that as dyspnoea decreases as a result of IMT, the subject spontaneously increases his or her physical activity, leading to improved physical deconditioning, which is not reflected in inspiratory muscle strength.

After IMT, Group 1 patients exhibited a significant fall both in $V'E$ and in $V'O_2$ during exercise, showing a significant correlation between both indices. Although this relationship may be considered spurious because $V'O_2$ is related to $V'E$, we can infer that the metabolic cost of a given level of exercise was lower after training, since patients diminished their ventilation. In Group 1, the level of $V'E$ during a mild exercise reached 74% of their estimated maximum voluntary ventilation (MVV) before training and decreased to 63% after IMT.

The contribution of respiratory muscle $V'O_2$ to total $V'O_2$ during a given exercise in COPD patients is expected to be increased, since it has been well-documented that the oxygen cost of increasing ventilation is high in these patients [21, 22]. In the present patients, peak $V'O_2$ was approximately 800 mL·min⁻¹, which was mildly reduced as compared to normal subjects of the same age [23]. The level of maximal exercise achieved by these patients however, was only 189 kpm·min⁻¹. This discrepancy between peak $V'O_2$ and workload suggests either that patients were physically deconditioned or that the oxygen cost of breathing accounted for a large proportion of their exercise $V'O_2$.

The present results are not in agreement with those reported by FLYNN *et al.* [10], who employed a similar training device. After 6 weeks of training, they observed a significant improvement in inspiratory muscle performance without changes in peak $V'O_2$, maximal workload and 12 MWD. The main difference between the study by FLYNN *et al.* [10] and the present study was

the length of the training period (6 vs 10 weeks), which could account for the different results on exercise performance.

$V'O_2$ and $V'E$ for the same level of exercise were reduced in patients trained with a load of 30% peak $P_{I,max}$, as compared with baseline evaluation. Although we cannot demonstrate a mechanism responsible for the fall in $V'E$ and $V'O_2$ during exercise after IMT with the present data, we can speculate on at least two possibilities that separately or together could be responsible for our findings. It is possible that with IMT, Group 1 patients could have achieved some degree of general physical training because of less dyspnoea and consequent increase in daily life activities [24]. CASABURI *et al.* [25] have recently demonstrated, in COPD patients, that exercise training diminishes lactic acid production during exercise, thus lowering the ventilatory drive, and, as a consequence, ventilation falls. As we did not measure lactic acid during the exercise test, we have no data to support this hypothesis. However, the significant correlation between the fall in $V'E$ and in $V'O_2$ during exercise observed in Group 1 patients leads us to postulate that a decreased respiratory stimulus could be an important mechanism responsible for the reduction in $V'E$ and in the metabolic cost of exercise.

Another possible explanation for the fall in $V'O_2$ during exercise after IMT is an increase in the efficiency of the respiratory pump. This effect could be due to changes in the pattern of recruitment of the inspiratory muscles during exercise or to a global increment in their efficiency, independent of the groups recruited during exercise. In support of this hypothesis, COUSER *et al.* [26] have recently demonstrated in COPD patients that training the upper extremities reduces the metabolic cost and the ventilatory requirements of elevating the arms, a manoeuvre that also elicits dyspnoea. The effects of IMT found in the present study could be analogous to this situation.

BOUTELLIER and PIWKO [27] and BOUTELLIER and co-workers [28] demonstrated, in normal sedentary and trained subjects, that IMT using isocapnic hyperventilation increases both respiratory and exercise endurance. They also observed a significant fall in $V'E$ and a reduction in blood lactate during exercise, that were attributed to a reduction in lactic acid production by the respiratory muscles after IMT. The fall in $V'E$ and $V'O_2$ that we observed during a progressive bicycle exercise after IMT is consistent with their results [26, 27]. To further evaluate the mechanisms involved in these effects, it could be useful to measure exercise endurance at a given percentage of the patient's maximal workload and to correlate changes in $V'E$ and $V'O_2$ with changes in respiratory efficiency measured during unloaded increasing ventilation.

In summary, the results of the present study demonstrate that inspiratory muscle training using a threshold device with a target load of 30% peak maximal inspiratory pressure relieves dyspnoea, improving performance of daily life activities, and reduces the metabolic cost of exercise in patients with chronic airflow limitation, an effect that could be explained by a reduction in minute ventilation during exercise or by some degree of physical training attained with inspiratory muscle training.

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