Respiratory Medicine (2007) **101**, 2297–2304

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Supervised high intensity continuous and interval training vs. self-paced training in COPD☆

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Received 1 April 2007; accepted 20 June 2007

KEYWORDS
Breathing pattern;
Chronic obstructive pulmonary disease;
Exercise capacity;
Interval training;
Lactic acidosis threshold

Summary

Background: Endurance training is an effective component of pulmonary rehabilitation in COPD. Controversy exists regarding whether different modalities of supervised exercise training (continuous (C) or interval (I)) or self-paced (S) programs are equally beneficial.

Methods: Seventy-one patients with COPD (average $FEV_1 = 55\%$ predicted) were assigned to 8 weeks of C, I or S training, 45 min/session, 3 times/week. Group C ($n = 22$) exercised at 80% of pre-training peak work rate in an incremental cycle ergometer test. In group I ($n = 17$), training consisted of 30 min of cycling 2 min at 90% followed by 1 min at 50% peak work rate bracketed by 7.5 min at 50% peak work rate. The S group ($n = 32$) was instructed to cycle, climb stairs and walk in their home with the same periodicity and time intervals.

Results: Improvement in incremental test peak work rate was significant in both C and I groups, but not in S. Peak oxygen uptake and lactic acidosis threshold improved significantly in the supervised groups, but differences among groups did not achieve significance. Scores in an activity questionnaire improved in all groups without significant differences among groups.

Conclusions: In COPD patients, continuous and interval training have similar physiologic effects; by some measures of endurance exercise performance, they are superior to self-paced training. However, all were effective in improving patient-perceived activity.

☆The work was performed at Department of Pulmonology, Szeged University, Deszk, Hungary. None of the authors received financial support from any commercial entities during the course and in regard with the study.

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0954-6111/$ - see front matter © 2007 Published by Elsevier Ltd.
doi:10.1016/j.rmed.2007.06.017

Introduction

Pulmonary rehabilitation is a routine part of management of chronic obstructive pulmonary disease (COPD) patients. Evidence-based analyses have concluded, from randomized, controlled trials, that exercise training improves exercise capacity and quality of life in COPD.[1] Breathlessness and peripheral muscle dysfunction leads to decreased ability to perform normal activities and reduces quality of life.[1] Exercise training has favorable effects on breathing, circulation and metabolism.[2] These physiologic effects depend on training frequency, intensity, modality, and duration; a variety of exercise training program characteristics have been employed in previous studies.[3–9]

In COPD, high intensity training results in greater physiologic benefit than lower intensity training.[3] Several authors have attempted to determine whether interval training, in which periods of higher intensity are alternated with periods of lower intensity, can achieve superior physiologic benefits compared to constant work rate (continuous) exercise training. In healthy subjects some,[10,11] but not all,[12–14] studies have demonstrated better results in selected physiologic parameters from interval vs. continuous training. In COPD, two studies have not detected differences between these training strategies.[4,8] Ambrosino reviewed the physiologic effects of interval training and found that it results in greater increase in peak oxygen consumption and peak work rate, a greater improvement in lactate threshold, and it is more easily accepted, especially in elderly people.[15] Ambrosino concluded that, in COPD patients, no clear superiority of high intensity bilevel interval training had been demonstrated.[15] Another major controversy exists regarding the value of self-paced training programs. These programs have yielded improved exercise capacity, reduced breathlessness and improved quality of life,[9] but whether these benefits are comparable to those achievable in supervised training programs is unclear.[6,7]

We felt that it would have great practical importance to determine the relative effectiveness of different rehabilitative training modalities in a systematic comparative study of COPD patients. Therefore, we examined the responses to supervised high intensity training utilizing either continuous or interval training profiles and compared these responses to those of a self-paced exercise program to determine whether there were differences in the improvements in exercise tolerance or in perceived activity levels among these three approaches. The results of this study give practical guidance for rehabilitation professionals seeking to institute effective rehabilitation interventions in COPD patients.

Material and methods

Study subjects

Seventy-one stable patients with COPD participated (Figure 1). As assessed by % predicted forced expired volume in 1 s (FEV_1)[16] severity ranged from mild to severe; none had qualified for long-term oxygen therapy. The study was approved by the local ethical committee and the patients gave consent for their participation. Subjects were screened for severe cardiovascular, neurological or exercise-limiting joint diseases that would have precluded full participation in the training protocol. Eight were excluded from 79 screened patients: 1 with psychiatric disease, 4 with ischemic heart disease and 3 had exercise-limiting joint disease (Figure 1).

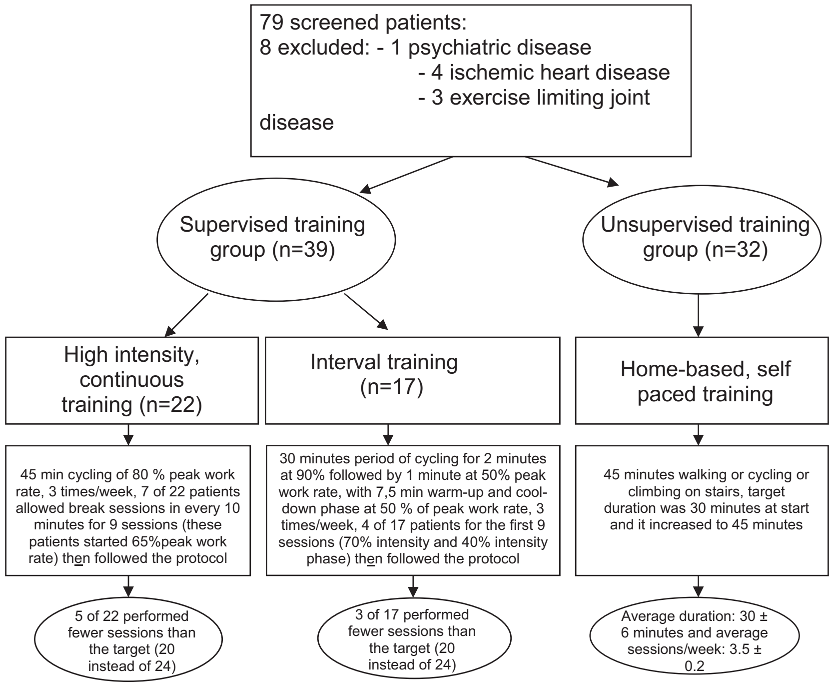

Figure 1 Flow of participants through each study stage.

Study design

Patients were divided into three groups: C, supervised continuous, $n = 22$; I, supervised interval, $n = 17$; and S, home-based and self-paced, $n = 32$ (Table 1, Figure 1). Patients who lived in the vicinity of the training center and could attend outpatient training sessions were randomized (without stratification) to C or I; those unable to attend supervised training due to unreasonable travel distances were assigned to self-paced training. It should be emphasized that assignment to the self-paced group was based on travel distance to the study center, not on motivation to participate in the training program. C and I groups performed exercise training 3 times/week for 45 min during an 8-week period. Group C exercise intensity was 80% of peak work rate achieved in an incremental exercise test (Figure 1). In 7 of the 22 patients in the C group breaks in the sessions were allowed up to every 10 min for up to the first 9 sessions and some of these patients also started at a training intensity lower than the target (about 65% of peak work rate). After the 9th session, all performed the target 80% intensity of pre-training maximal work rate (Figure 1). Interval training involved a 30 min period of cycling for 2 min at 90% followed by 1 min at 50% peak work rate. This 30 min period was preceded and followed by approximately 7.5 min of exercise at 50% peak work rate (warm-up and cool-down phase) (Figure 1). Four of 17 patients in the I group were initially unable to tolerate this regiment in initial sessions and instead performed approximately 70% intensity in the high intensity phase and 40% intensity in the low intensity phase for the first nine sessions, then performed the target protocol in the rest of the training sessions (Figure 1). The S group was instructed to cycle, climb stairs and walk in their natural environment with the same weekly periodicity and time interval as used in in-center programs for 8 weeks (Figure 1). The target duration of the cycling was 30 min at the start of the training; this increased to a target of 45 min as training proceeded. Subjects were instructed to adjust cycle work rate to the maximal load the patient could tolerate. Patients were also instructed to walk on flat ground for the same duration as they cycled at the highest speed they could tolerate. There was a third option to climb stairs with the same duration and maximal intensity they could tolerate. Almost half of the patients (15/32) had about 25 min maximal training duration, so the average duration was 30 min. Some patients (10/32) were called monthly and were asked about their condition and training regimen. Subjects in S completed logs reporting date and duration of training sessions.

Pulmonary function and exercise testing

Patients performed a series of pulmonary function tests (V_{max} 229 and Autobox 6200, Sensormedics, Yorba Linda, CA) including spirometry, body plethysmography and diffusion capacity. Normal values were those of Knudson et al.,[16] Goldman and Becklake[17] and Crapo and Morris,[18] respectively. Patients inhaled 400 μg of salbutamol via a spacer 20 min before testing.

Incremental exercise tests were performed on an electronically braked cycle ergometer (Ergoline-900, Marquette). After 3 min rest and 3 min constant pedaling at 20 W, work rate was increased 5, 10 or 15 W/min in ramp profile. Ramp slope was: $FEV_1 < 1.0$ L—5 W/min, $FEV_1 > 1.0$ L—10 W/min, $FEV_1 > 1.5$ L—15 W/min. Pedaling rate was kept constant at approximately 60 rpm. Pulmonary ventilation ($\dot{V}_E$) and gas exchange (oxygen uptake ($\dot{V}O_2$) and carbon dioxide output ($\dot{V}CO_2$)) were measured breath-by-breath by a mass flow-sensor and exercise metabolic measurement system (V_{max} 29c, SensorMedics). The system was calibrated before each test. Lactic acidosis threshold (LAT) was identified by the modified V-slope method.[19] Heart rate, 12-lead ECG (Cardiosoft, SensorMedics) and oxygen saturation by pulse oximetry (SatTrak, SensorMedics) was monitored. Blood gas analysis was done from capillary blood taken from a hyperemic earlobe at rest and peak exercise (AVL Omni7, Ramsey, MN). Maximal voluntary ventilation was estimated as $40 \times FEV_1$.[20] Breathlessness and leg fatigue were evaluated at peak exercise by modified Borg score.[21] Isotime response, defined as response at the time the shorter of the pre- and post-training incremental exercise test ended, was calculated for several physiological variables.

Activity

Activity was assessed by a questionnaire previously used in this laboratory,[22] which includes questions evaluating difficulty in walking, climbing stairs, dressing, cleaning, shopping, housekeeping, working and hobby. Daily activity was scored on a 0–3 scale (0: not limited, 1: moderately limited, 2: severely limited, 3: not able to do) for eight items before and after training with total score of

Table 1 Demographic characteristics of the study participants.

	Supervised continuous (C) group ($n = 22$)	Supervised interval (I) group ($n = 17$)	Self-paced (S) group ($n = 32$)
Age (year)	61±12	67±10	60±12
Height (m)	1.67±0.07	1.66±0.07	1.68±0.06
Body weight (kg)	73±12	67±10	71±12
BMI (kg/m^2)	26±4	25±4	25±4
Male:female	19:3	11:6	25:7

Mean±S.D. BMI: body mass index.

0–24 ($\leqslant$5: good activity, 5–8: moderately reduced activity, 8–16: severely reduced activity, $>$16: homebound).

Statistical analysis

Comparison between after vs. before training values and responses of different groups were made by repeated measures two-way analysis of variance (ANOVA) (Sigmastat 3.1). Significance was accepted at $p<0.05$. Distribution around the mean was expressed ±S.D., except in figures, where ±S.E. was utilized. Distributions were tested for normality by Kolmogorov–Smirnov test and significance was accepted if $p<0.05$. We targeted the study sample size based on discerning differences in the change in peak oxygen uptake in the incremental test among groups as the primary outcome. We used ANOVA statistics for the three groups and asserted that the minimum clinically important difference between groups was 0.1 L/min,[23] the expected standard deviation of change in peak oxygen uptake among subjects was 0.1 L/min, and utilized a power of 0.8 and $\alpha=0.05$. This analysis indicated that 20 subjects in each group would be required.

Results

In the supervised groups, 31 of 39 subjects trained 3 times/week (total 24 sessions) (Figure 1). Five of 22 continuous training patients performed fewer sessions than the target, averaging 20 sessions (Figure 1). In the interval group 3 of 17 patients performed fewer sessions than the target, also averaging 20 sessions (Figure 1). Training work rate of supervised continuous training was 74±28 W (80% peak work rate). In the interval group work rate fluctuated between 79±25 W (90% peak work rate) and 44±14 W (50% peak work rate). Therefore, over the course of a session, the average work rate was 80% of peak work rate in the C group and 77% in the I group. The actual mean works in the two groups were 161.6±50.6 and 199.8±74.8 kJ in the I and C groups, respectively. The self-paced group's activity logs revealed average daily training duration was 30±6 min and average sessions/week was 3.5±0.2.

All subjects completed the training protocol. There were no adverse events attributable to the study protocol.

Demographics for study participants are presented in Table 1; there were no significant differences among the three groups. Lung function showed moderate obstruction and hyperinflation at baseline without significant differences among groups. There were no significant changes after training (Table 2).

Percent predicted peak work rate[24] was 67%, 67%, 68% in C, I, and S groups, respectively, before training. Peak $\dot{V}_E$ and $\dot{V}_E$/MVV ratio before training did not differ significantly among groups (Table 3), suggesting that degree of ventilatory limitation was similar. Further supporting this, peak exercise Borg dyspnea scores did not differ among groups. In response to exercise training, peak work rate increased significantly in C and I, but not in S (Figure 2) with increases in C and I groups (12±9 and 14±12 W, respectively, $p<0.05$ for each) that were greater than in S (3±12 W, NS). Similarly, peak $\dot{V}O_2$ increased significantly in C and I groups, but not in S; however, differences among groups were not statistically significant (Figure 2). LAT increased significantly in supervised groups, averaging 0.08±0.10 and 0.10±0.15 L/min in C and I, but not in S (0.04±0.21 L/min) although, again, these differences did not achieve statistical significance. Peak $\dot{V}_E$, heart rate, blood gases, oxygen saturation (SpO_2) and Borg dyspnea and leg effort scores did not change significantly as a result of training in any group, suggesting that exercise proceeded to similar physiologic limitations.

Isotime responses are presented in Table 3 and Figure 3. There were significant reductions in isotime ventilatory equivalent for CO_2 ($\dot{V}_E/\dot{V}CO_2$) and respiratory rate (f) and

Table 2 Resting lung function and blood gasses before and after rehabilitation.

Lung function	Supervised continuous (C) group ($n=22$)		Supervised interval (I) group ($n=17$)		Self-paced (S) group ($n=32$)	
	Before training	After training	Before training	After training	Before training	After training
FEV_1 (L)	1.5±0.5	1.5±0.5	1.7±0.7	1.8±0.7	1.5±0.5	1.5±0.5
FEV_1 (% predicted)	51±16	52±17	64±29	66±23	52±16	52±17
FVC (L)	2.9±0.8	3.0±0.8	3.0±0.7	3.1±0.8	3.0±0.7	3.0±0.7
FVC (% predicted)	82±17	82±15	90±23	93±22	84±17	86±19
FEV_1/FVC (%)	50±12	49±12	57±17	57±16	50±13	49±12
TLC (% predicted)	110±16	110±17	116±13	111±21	119±16	117±21
FRC (% predicted)	136±33	139±34	147±33	140±39	157±30	153±40
RV (% predicted)	164±48	160±42	171±53	149±46	179±44	176±52
RV/TLC (%)	54±10	52±10	54±13	48±7	56±11	55±10
D_LCO (% predicted)	67±17	69±20	67±26	65±13	62±26	63±21
PaO_{2rest} (mmHg)	65±8	64±6	67±7	73±15	66±7	65±7
$PaCO_{2rest}$ (mmHg)	43±4	42±4	42±7	39±5	42±5	43±6

Mean±S.D., FEV_1: forced expiratory volume in 1 s, FVC: forced vital capacity, TLC: total lung capacity, FRC: functional residual capacity, RV: residual volume, D_LCO: diffusion capacity of carbon monoxide, PaO_2: arterial partial O_2 pressure, $PaCO_2$: arterial partial CO_2 pressure.

Table 3 Exercise testing results before and after rehabilitation.

		Supervised continuous (C) group		Supervised interval (I) group		Self-paced (S) group	
		Before training	After training	Before training	After training	Before training	After training
Peak	$\dot{V}O_2$ (L/min)	1.17±0.40	1.27±0.40*	1.10±0.31	1.18±0.36*	1.12±0.37	1.17±0.35
	$\dot{V}_E$ (L/min)	51±17	51±16	46±11	49±14	48±12	47±11
	f (breaths/min)	45±7	41±7*	44±6	42±7	44±6	41±7*
	HR (beats/min)	138±26	133±22	130±17	129±36	139±24	138±22
	SpO_2 (%)	93±2	94±2	92±6	94±2	92±2	92±4
	$\dot{V}_E/\dot{V}CO_2$	40±5	37±4	39±5	38±4	43±10	41±7
	$\dot{V}_E$/MVV (%)	90±24	89±22	68±29	76±24	85±19	83±22
	PaO_2 (mmHg)	71±10	69±10	67±7	70±14	68±9	68±11
	$PaCO_2$ (mmHg)	43±6	44±7	42±7	42±5	44±5	43±6
	Borg (dyspnea)	6.4±2.5	5.7±2.7	6.6±2.2	6.0±2.1	7.4±1.8	6.7±2.5
	Borg (leg fatigue)	6.2±2.9	5.9±3.1	6.9±2.2	6.1±2.5	6.6±2.3	6.3±2.6
LAT	$\dot{V}O_2$ (L/min)	0.82±0.22	0.92±0.24*	0.83±0.29	0.96±0.28*	0.84±0.25	0.91±0.25
	$\dot{V}_E$ (L/min)	32±7	36±7	32±8	35±9	33±7	36±7
	f (breaths/min)	27±5	27±6	29±6	30±5	26±4	27±4
	HR (beats/min)	119±23	111±23	110±19	114±18	120±20	121±19
	SpO_2 (%)	93±2	94±2	94±2	93±6	93±2	93±4
	$\dot{V}_E/\dot{V}CO_2$	41±6	38±11	41±5	40±6	43±10	43±8
Isotime	$\dot{V}O_2$ (L/min)	1.14±0.37	1.15±0.35	1.07±0.26	1.06±0.34	1.10±0.35	1.11±0.33
	$\dot{V}_E$ (L/min)	48±16	46±16	42±10	42±14	45±10	44±10
	f (breaths/min)	33±6	30±6*	33±7	31±7	31±6	31±7
	HR (beats/min)	139±24	130±19	127±17	125±20	136±23	133±21
	SpO_2 (%)	93±3	93±3	93±3	92±5	92±3	92±4
	$\dot{V}_E/\dot{V}CO_2$	41±6	38±5*	38±7	41±8	41±8	41±7

Mean±S.D., $^*p<0.05$, $\dot{V}O_2$: oxygen uptake, $\dot{V}_E$: minute ventilation, f: breathing rate, HR: heart rate, SpO_2: oxygen saturation, $\dot{V}_E/\dot{V}CO_2$: ventilatory equivalent, MVV = $FEV_1 \times 40$: maximal voluntary ventilation.

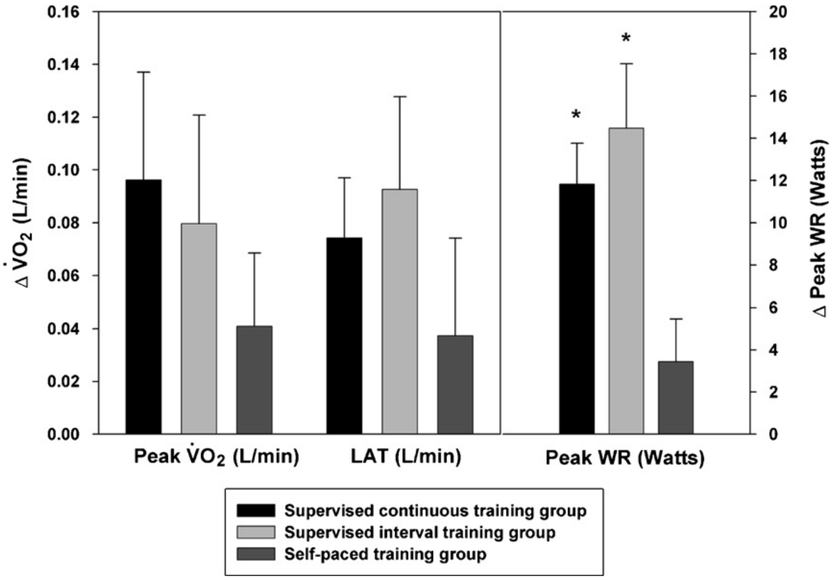

Figure 2 Change in peak oxygen uptake ($\dot{V}O_2$), the lactic acidosis threshold (LAT) and peak work rate as a result of training in the three training groups. $^*p<0.05$ vs. self-paced training, errors bars represent ±S.E.

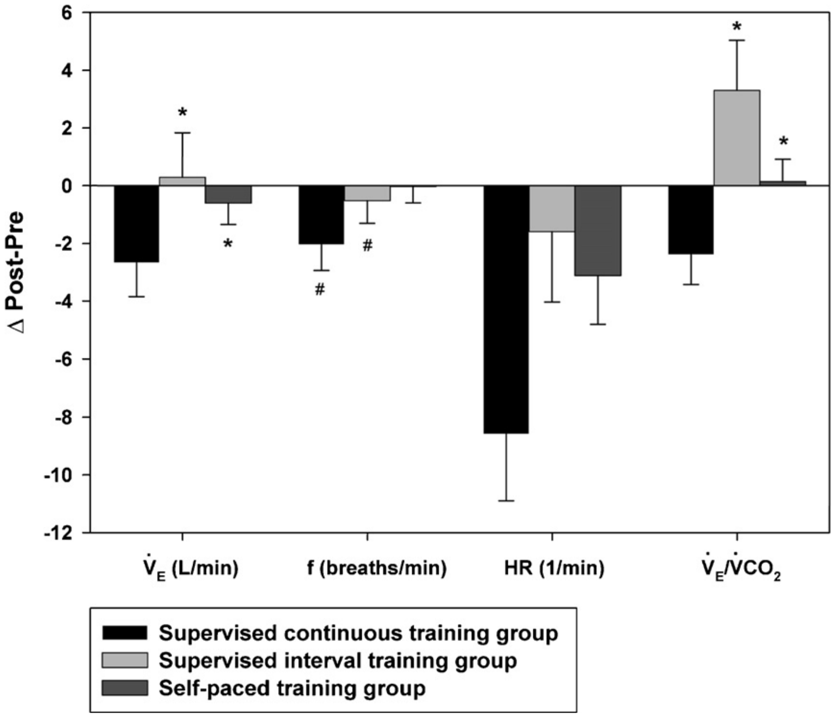

Figure 3 Change in isotime responses as a result of training during an incremental exercise test in the three training groups. $\dot{V}_E$, minute ventilation; *f*, respiratory rate; HR, heart rate; $\dot{V}_E/\dot{V}CO_2$, ventilatory equivalent for carbon dioxide. $^{*}p<0.05$ vs. supervised continuous training, $^{\#}p<0.05$ vs. self-paced training, error bars represents ±S.E.

non-significant reduction tendencies in isotime $\dot{V}_E$ and heart rate (HR) in the supervised constant intensity group (by an average of 3 units, 3 breaths/min, 2 L/min and 9 beats/min, respectively). In contrast, changes in isotime responses in the I and S groups were small and did not achieve statistical significance.

The activity questionnaire showed that, at baseline, all groups had reduced activity (average score: 11). After training, there was significant improvement (i.e., decrease) in activity score in each group (C: 11.5±0.7 vs. 9.0±2.8, I: 10.4±2.4 vs. 7.2±2.1, S: 11.6±2.3 vs. 7.0±1.9; in C, I and S groups; each $p<0.01$ before vs. after training) but differences in improvement among groups were non-significant.

Discussion

We compared three rehabilitative training strategies and assessed their effectiveness in increasing peak exercise tolerance and in demonstrating physiological training effects. Two training modalities were supervised continuous and interval training methods; these effects were compared to a self-paced, home-based program. Significant improvement was detected in peak work rate in an incremental exercise test in the supervised groups, with little difference between C and I groups. Both supervised groups exhibited similar significant increases in $\dot{V}O_{2peak}$ and LAT. Self-paced training yielded only small and insignificant improvements in these measures. Analysis of variance revealed that the difference in increase in peak work rate, but not $\dot{V}O_{2peak}$ and LAT between the supervised groups and the self-paced groups achieved statistical significance.

COPD patients apparently become deconditioned because activity becomes progressively limited by shortness of breath.[1,2] In their muscles of ambulation, aerobic enzyme concentrations, mitochondrial density, muscle fiber-to-capillary ratio decrease, and there is reduction of muscle mass and type I fiber fraction.[25]

Although it had previously been doubted that COPD patients could achieve a physiological training effect, it has now been clearly shown that high intensity endurance training yields increases in $\dot{V}O_{2peak}$[3] and the ability to sustain a given work rate.[26] Moreover, muscle biopsy has shown that training is capable of increasing the muscle capillary-to-fiber ratio leading to a reduction in capillary to mitochondria diffusion distance[27] and increasing oxidative enzyme content and myoglobin levels.[27]

Optimal strategies to increase exercise tolerance through rehabilitative exercise have been sought. A key finding has been that high intensity training engenders greater physiologic responses than low intensity training.[3] Recent studies have focused on strategies allowing COPD patients to exercise at higher training work rates; in randomized double-blind trials, oxygen administration[26] and bronchodilator therapy[28] have been shown to increase rehabilitative exercise training effectiveness.

Home-based exercise programs have been shown effective in increasing exercise tolerance and quality of life,[5] though without concurrent comparison with supervised programs relative effectiveness cannot be judged. Home-based programs have discernable disadvantages. Frequent encouragement and instruction by trained rehabilitation personnel are felt to be important adjuncts to rehabilitation. Ongoing interaction with patients similarly afflicted is posited to assist in motivating patients to comply with rehabilitative therapy. It is therefore important to compare effectiveness of home-based programs with supervised group programs; only two such studies have been reported.[6,7]

Strijbos et al. compared responses of COPD patients to a 12-week program with twice-weekly sessions of either home-based (15 patients) or in-center exercise (15 patients).[7] Equal improvements in exercise capacity and reduction in breathlessness and leg fatigue were found at the program's end and 3 months later in the two groups. However, some benefits (exercise capacity and Borg dyspnea score) persisted to a greater extent in the home-based program after 18 months. An important study feature was that therapists visited the home for each exercise session; this is not practical in many settings and is not a feature of most home-based programs that have been reported. Puente-Maestu et al. compared responses of 41 COPD patients to 8 weeks of in-center rehabilitation 4 times/week vs. a home-based program with weekly in-center visits to encourage adherence.[6] Estimated mean training work rate was substantially greater in the in-center rehabilitation group and exercise tolerance measures (exercise duration, $\dot{V}O_{2peak}$, heart rate, isotime $\dot{V}_E$, $\dot{V}CO_2$ and lactate accumulation) also showed greater improvement in the in-center program.

In the present study, the home-based program employed was more similar to that of Puente-Maestu et al.[6] than to that of Strijbos et al.[7] in that home rehabilitation personnel visits were not included. Like Puente-Maestu, we found only small non-significant trends in physiological training measures. While home-based training may improve the patient's perception of activity level (as indicated by our activity questionnaire), it seems inferior to supervised training in improving exercise endurance. We detected only small non-significant improvement in peak exercise capacity, ventilatory, cardiovascular and metabolic responses; improvement in peak exercise tolerance was significantly less than in supervised groups. We speculate that supervised training in a supportive environment in the presence of others similarly afflicted results in superior training results.

Effectiveness of interval training is conceptually dependent on the relationship between training intensity and its effectiveness in inducing training effects in the exercising muscles.[15] Traditionally, it has been asserted that there is a ''critical training intensity'' below which no training effects will accrue, no matter how long training proceeds. Above this threshold,[3] progressively higher intensities yield progressively greater training effects, although it is not certain that this relationship is linear. If, for example, continuous training with intensity set at the critical training intensity is compared with interval training where intensity fluctuates below and substantially above the critical intensity it is reasonable to expect that interval training will be more effective. Alternately, if continuous training occurs at a work rate above the critical training intensity and this is compared to interval training with work rate fluctuating around this mean but always remaining above the critical intensity, it is difficult to predict which will be more effective (including the possibility that continuous training may be more effective than interval training).[8] Moreover, it is difficult to predict which regimen will be better tolerated in the sense that the total tolerable work may be greater with one or the other strategy.

Coppoolse et al. studied 21 COPD patients who performed an 8-week 5-sessions/week, 30-min/session exercise program in which intensity was randomized to a continuous or interval training profile with the same total work per session.[4] Exercise testing revealed that, for most response measures, physiologic changes were more marked in the continuous training group.[4]

Vogiatzis et al. studied 36 COPD patients who engaged in endurance training with 40-min sessions held twice weekly. Subjects were randomized to perform a constant work rate at 50% of peak work rate or 30 s at 100% of peak work rate alternating with 30 s of rest.[8] Both groups demonstrated physiologic benefits, but they did not differ.[8]

Puhan et al.[29] recently found no significant differences between interval training and constant work rate training as regards improvement of exercise capacity and quality of life in COPD patients. However, the work intensities used in this study were somewhat lower than used in previous studies[4,8] or in the present study: training work rate in the constant work rate group was only 57% of peak work rate achieved in an incremental test and the total work per session of those performing interval training was only 76% of that performed by the constant work rate training group. Further, the duration of the training sessions was only 20 min in either group.

In the present study, both supervised training groups utilized work rate profiles designed to be high intensity. The continuous training group exercised at 80% peak work rate in an incremental exercise test. This is similar to the strategy we employed previously[3] and is a near-maximal target.[30] Interval training allowed a substantial fraction of the time (2/3) to be spent at an even higher training intensity: 90% peak work rate, with the other 1/3 spent at lower intensity (50% peak work rate). The average exercise intensity was therefore 77% of peak work rate and similar to that of the continuous work rate group. As shown in Figures 1 and 2, interval and continuous work rate profiles yielded similar physiologic response changes and therefore similar training effects.

It should be noted that, in both supervised groups, exercise intensity was held constant during the training program in order to enable strict comparison between the two strategies. This contrasts to most previous reports of exercise training in COPD in which training intensity was advanced as tolerated during the intervention. The latter strategy generally allows substantially higher training work rates as the program proceeds (e.g., patients able to exercise for the entire session at work rates approximating the peak in pre-training incremental exercise testing).[26] This might explain why training-induced increases we observed in the supervised groups in, for example, $\dot{V}O_{2peak}$ are somewhat less than in some other COPD training studies.

In summary, this study supports the concept that in-center high intensity supervised rehabilitation programs are more likely to yield physiologic evidence of improved exercise tolerance than home-based unsupervised programs although by some of the measures of endurance exercise performance we employed, this difference did not achieve statistical significance. We did not succeed in demonstrating a difference in effectiveness of interval training as compared with constant work rate training with similar total work per session. Future studies might explore other interval work rate profiles that might prove more effective.

Conflict of interest

The authors have no conflict of interest regarding the subject matter of this research.

Acknowledgments

This study was supported by funds available to the Department of Pulmonology, Szeged University, Deszk, Hungary. Dr. Casaburi occupies the Grancell/Burns Chair in the Rehabilitative Sciences at the Los Angeles Biomedical Research Institute.

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