Aerobic and Strength Training in Patients with Chronic Obstructive Pulmonary Disease

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The purpose of this study was to evaluate whether strength training is a useful addition to aerobic training in patients with chronic obstructive pulmonary disease (COPD). Forty-five patients with moderate to severe COPD were randomized to 12 wk of aerobic training alone (AERO) or combined with strength training (AERO + ST). The AERO regimen consisted of three weekly 30-min exercise sessions on a calibrated ergocycle, and the ST regimen included three series of eight to 10 repetitions of four weight lifting exercises. Measurements of peripheral muscle strength, thigh muscle cross-sectional area (MCSA) by computed tomographic scanning, maximal exercise capacity, 6-min walking distance (6MWD), and quality of life with the chronic respiratory questionnaire were obtained at baseline and after training. Thirty-six patients completed the program and constituted the study group. The strength of the quadriceps femoris increased significantly in both groups ($p < 0.05$), but the improvement was greater in the AERO + ST group (20 ± 12% versus 8 ± 10% [mean ± SD] in the AERO group, $p < 0.005$). The thigh MCSA and strength of the pectoralis major muscle increased in the AERO + ST group by 8 ± 13% and 15 ± 9%, respectively ($p < 0.001$), but not in the AERO group (3 ± 6% and 2 ± 10%, respectively, $p > 0.05$). These changes were significantly different in the two study groups ($p < 0.01$). The increase in strength of the latissimus dorsi muscle after training was modest and of similar magnitude for both groups. The changes in peak exercise work rate, 6MWD, and quality of life were comparable in the two groups. In conclusion, the addition of strength training to aerobic training in patients with COPD is associated with significantly greater increases in muscle strength and mass, but does not provide additional improvement in exercise capacity or quality of life. Bernard S, Whittom F, LeBlanc P, Jobin J, Belleau R, Bérubé C, Carrier G, Maltais F. Aerobic and strength training in patients with chronic obstructive pulmonary disease.

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Although exercise training is now recognized as an essential component of pulmonary rehabilitation (1, 2), there is no consensus about the optimal training strategy for this purpose (3). Lower-extremity aerobic training consistently improves exercise tolerance in patients with chronic obstructive pulmonary disease (COPD), but has little effect on muscle atrophy and weakness, two problems common in patients with COPD and which can contribute to their poor exercise tolerance and quality of life (4–6).

Strength training can promote muscle growth and strengthening in normal subjects (7), and may therefore represent a useful addition to whole-body aerobic training in patients with COPD. In addition to improving peripheral muscle function, this training modality may enhance exercise tolerance in patients with COPD. A greater strength of the quadriceps femoris muscle after training may reduce the perception of muscle fatigue, a common limiting symptom during exercise in patients with COPD (5, 8). In older normal subjects, strength training has also been associated with modest but significant increases in skeletal muscle oxidative capacity (9), another potential factor involved in exercise intolerance in patients with COPD (10).

Simpson and colleagues have reported that 8 wk of strength training produces an improvement in muscle strength and in submaximal exercise tolerance in patients with COPD (6). In patients with coronary heart disease, strength and aerobic training have complementary effects on peripheral muscle function and exercise capacity (11). On the basis of these observations, we were interested in evaluating whether strength training would provide any additional benefits in COPD patients involved in an aerobic training program. Accordingly, the aim of the present study was to compare the effects of aerobic training alone and in combination with strength training on peripheral muscle mass and strength, exercise tolerance, and quality of life in patients with COPD.

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METHODS

Subjects

Forty-five patients with COPD (12 females and 33 males) were recruited for this study. The diagnosis of COPD was based on smoking history and on pulmonary function tests showing irreversible bronchial obstruction (12–15). The patients were stable at the time of entry into the exercise program, and none had clinical evidence of exercise-limiting cardiovascular or neuromuscular diseases. The research protocol for the study was approved by the ethics committee of our institution, and written consent was obtained for each participant.

Study Design

In the rehabilitation program conducted at our institution, patients are recruited in blocks of 12 to 14. They are then divided into two groups in order to facilitate supervision and coaching during exercise sessions. For the purpose of our study, four blocks of patients were successively recruited. Patients in the first three blocks were randomly divided into two groups for each block, who underwent either aerobic training alone (AERO; n = 19) or combined with strength training (AERO + ST; n = 17). Only nine patients could be recruited for the fourth block. To facilitate their supervision during training, it was decided to assign these nine patients to only one training modality, AERO + ST. The choice of this training modality was made in a random manner (toss of a coin). Accordingly, the AERO group included 19 patients, whereas the AERO + ST group contained 26 patients.

Exercise Training

The 12-wk training program included a period of aerobic training that was supplemented with a 45-min period of relaxation and breathing exercises for the AERO group and a 45-min period of strength training for the AERO + ST group. The relaxation was done in a semirecumbent position, and the breathing exercises consisted of diaphragmatic and pursed-lip breathing and effective coughing techniques. During the training sessions, each group was closely supervised by a physiotherapist or an exercise physiologist.

Aerobic training. The aerobic training consisted of leg exercise on a calibrated ergocycle (Monark; Monark-Crescent, Varberg, Sweden) for 30 min in each of three weekly sessions. We aimed at high-intensity training, and the work rate corresponding to 80% of the peak work rate achieved during the baseline incremental exercise test was selected as the target training intensity. The physiotherapist or exercise physiologist was aware of the training intensity prescribed for each patient, and encouraged him or her to reach it. The intensity and duration of training were monitored as previously described (16). Supplemental oxygen was used during training for five patients in the AERO group and six in the AERO + ST group for persistent daytime hypoxia (n = 3) or exercise-induced oxygen desaturation (Sa_{O_2} < 90%) (n = 8).

Strength training. The strength training program included different exercises involving four muscle groups, which were performed with the following weight-lifting procedures: (*1*) a seated press (mainly for strengthening of the pectoralis major muscle); (*2*) a bilateral movement combining elbow flexion and shoulder adduction (mainly for the latissimus dorsi); (*3*) a leg press (mainly for the gluteus maximus); and (*4*) a bilateral knee extension (mainly for the vastus lateralis muscle). During the first 2 wk of the program patients were asked to perform two sets of eight to 10 repetitions of each exercise at a workload of 60% of the one repetition maximum (1 RM). This was progressively increased to three sets of eight to 10 repetitions at 80% of 1 RM. Thereafter, the training workload was increased when more than 10 repetitions per set could be performed.

Evaluation

Subjects were evaluated 1 or 2 wk before and at the end of the 12-wk exercise training program.

Pulmonary function tests. Standard pulmonary function tests, including spirometry, lung volume measurement, and measurement of the single-breath diffusion capacity for carbon monoxide ($D_{L_{CO}}$), were conducted at baseline according to previously described guidelines (12), and were related to normal values of Knudson and colleagues (13), Goldman and Becklake (14), and Cotes and Hall (15), respectively. Only spirometry was repeated at the second evaluation.

Computed tomography. A computed tomographic scan of the right and left thigh, halfway between the pubic symphysis and the inferior condyle of the femur, was done with a fourth-generation scanner (Model 900S; Toshiba Inc., Tokyo, Japan). Each image was 10 mm thick and was taken at 120 kV and 200 mA with a scanning time of 1 s while the subject was lying in the supine position. The thigh muscle cross-sectional area (MCSA) was obtained by measuring the surface area of the tissue with a density of 40 to 100 Hounsfield units (HU). This range of density was chosen because it corresponds to the density of muscle tissue (17) and eliminates the bone and fat components. All computed tomographic images were analyzed blindly by one investigator (G.C.). The bilateral thigh MCSA was calculated by adding the values for the right and left thighs, and was used for data analysis.

Strength measurements. Measurement of maximal voluntary strength of the quadriceps, femoris, pectoralis major, and latissimus dorsi muscles was made during dynamic contractions against hydraulic resistance (HF STAR, Hydrafitness Total Power; Henley Health Care, Belton, TX), as previously reported (18). The strength of the three muscle groups was measured with the subject seated comfortably and performing a rapid and powerful movement of the chosen body segment. The strength of the lower limbs was measured during bilateral knee extension (mainly involving the quadriceps femoris); that of the shoulder girdle was measured during a seated press (mainly involving the pectoralis major muscles) and a bilateral movement combining elbow flexion and shoulder adduction (mainly involving the latissimus dorsi muscles). To ensure that the best possible efforts were measured, subjects were carefully instructed to exert maximal effort at high velocity for each of six resistance levels, and were closely supervised during the procedure. The three lowest hydraulic levels were used to familiarize the subjects with the technique. The same movements were repeated at the higher levels until the generated strength reached a plateau. Two sets of measurements, separated by 30 min, were made for each muscle group, and the highest of the two values obtained was reported.

Exercise test. After an arterial cannula was placed in a radial artery, subjects were seated on an electrically braked ergocycle (Quiton Corival 400; A-H Robins Company, Seattle, WA) and connected to the exercise circuit through a mouthpiece. The exercise circuit consisted of a pneumotachograph, O_2 and CO_2 analyzers, and a mixing chamber (Quinton Qplex; A-H Robins). After 5 min of rest, the patient performed a progressive stepwise exercise test to maximum individual capacity. Five-breath averages of ventilation ($\dot{V}E$), oxygen uptake ($\dot{V}O_2$), and CO_2 exhalation ($\dot{V}CO_2$) were measured at rest and during exercise. Each exercise step lasted 1 min, and stepwise increments of 10 W were used. During exercise, arterial blood was sampled at 1-min intervals for determination of the lactic acid concentration. Blood samples were placed on ice until the end of the exercise test, at which time they were centrifuged at room temperature. Plasma lactic acid concentrations were measured with an enzymatic technique (Kit lactate; Boehringer Mannheim, Mannheim, Germany). Blood gases were also analyzed with the patient at rest and at maximal exercise capacity. The peak values for $\dot{V}O_2$ and exercise work rate were related to the normal values of (19).

6MWD. The 6MWD test was done in a long hall in which the patients could walk freely around two cones separated by 20 m. They were asked to walk as far as possible for 6 min with standardized encouragement (20). Three trials were done, and the best of the three was used for data analysis.

Quality of life. Health-related quality of life was assessed with the Chronic Respiratory Questionnaire (CRQ) (21). A recently validated French Canadian version was used (22), and was administered by a trained interviewer.

Data and Statistical Analysis

Values are reported as means ± SD. The average training intensity for a given training week was obtained by dividing the total work performed during that week by the duration of the training during the week. Physiologic parameters during exercise were compared at peak exercise and also at an identical exercise work rate (isoexercise) that corresponded to the greatest exercise work rate achieved at both of the two study evaluations. For each group, pre- and post-training comparisons were made, using a repeated measures design. The magnitude of the pre- and posttraining changes in the two study groups was compared through the use of a two-way analysis of variance (ANOVA) (group, training effect), with repeated measures for the second factor (training effect). A value of $p < 0.05$ was considered statistically significant.

RESULTS

Nine patients (four in the AERO group and five in the AERO + ST group) failed to complete the program because of exacerbations of COPD requiring hospitalization (n = 3), lower limb injury unrelated to the program (n = 1), surgery that could not be postponed (n = 3), amyotrophic lateral sclerosis that was diagnosed at the beginning of the program (n = 1), and uncontrolled diabetes mellitus (n = 1).

Baseline characteristics of the remaining 36 patients, who constituted the study population, are presented in Table 1. On average, patients had a normal body mass index (BMI), moderate to severe airflow obstruction, a slightly reduced Pa_{O_2}, and a normal resting P_{CO_2}. No significant difference between the two study groups was found for these variables, although the FEV_1% predicted tended to be greater in the AERO + ST group than in the AERO group. No change in these variables occurred with training (data not shown). No differences in age, gender distribution, BMI, or pulmonary function were found in patients belonging to the first three blocks and the nine patients of the fourth block (data not shown). None of the patients was employed; all were either retired or disabled because of severe respiratory impairment.

Amount of Training

The attendance rate at the training sessions averaged 92 ± 9% and 94 ± 4% in the AERO and AERO + ST groups, respectively. The most common reasons for missing exercise sessions were fatigue, transient worsening of dyspnea not requiring modification of the usual bronchodilator therapy, and transportation difficulties. The average amount of training during each training sessions is provided in Table 2. The duration of aerobic training was comparable in the two study groups. As a result of a greater baseline exercise capacity, the average absolute training intensity was significantly greater in the AERO + ST group than in the AERO group ($p < 0.05$). However, when the training intensity was expressed as a percent of the baseline peak exercise capacity, no difference was found for the two groups. The strength training objectives were achieved for the four muscle exercises in the AERO + ST group, as indicated by the number of sets and repetitions per set performed for each muscle exercise and the training workloads, which were close to their target values. No injury occurred with either training modality.

Effects of Exercise Training on Peripheral Muscle Function

In the AERO + ST group, there was an 8% increase in bilateral thigh MCSA after training, from 160 ± 36 cm^2 to 171 ± 38 cm^2 ($p < 0.0001$); a 20% increase in the strength of the quadriceps, from 57 ± 20 kg to 67 ± 21 kg ($p < 0.0001$); a 15% increase in the strength of the pectoralis major, from 64 ± 16 kg to 73 ± 17 kg ($p < 0.0001$), and an 8% increase in the strength of the latissimus dorsi, from 53 ± 12 kg to 56 ± 11 kg ($p < 0.05$). The quadriceps strength also increased significantly after training in the AERO group, from 51 ± 14 kg to 55 ± 15 kg ($p < 0.005$), but the other muscle characteristics did not change significantly in this group (160 ± 27 cm^2 versus 164 ± 30 cm^2, 60 ± 14 kg versus 61 ± 14 kg, and 47 ± 11 kg versus 48 ± 9 kg for the bilateral thigh MCSA, pectoralis major strength, and latissimus dorsi strength before and after training, respectively; $p > 0.05$).

Effects of Exercise Training on Exercise Capacity and Quality of Life

The physiologic parameters obtained at peak exercise are shown in Table 3. Peak exercise work rate increased by 19% and 12% in the AERO and AERO + ST groups, respectively, but this reached statistical significance only in the AERO + ST group ($p < 0.05$). No changes in peak $\dot{V}_{O_2}$, $\dot{V}_E$, heart rate, or arterial lactate concentration were found in either study group. In contrast, significant reductions in $\dot{V}_E$ (6%, $p < 0.05$),

TABLE 1

PATIENT CHARACTERISTICS*

	Pretraining	
	Aerobic Training (*n = 15*)	Aerobic + Strength Training (*n = 21*)
Age	67 ± 9	64 ± 7
Sex, M/F	11/4	17/4
Height, m	1.64 ± 0.09	1.67 ± 0.09
Weight, kg	67 ± 14	72 ± 18
Body mass index, kg/m^2	25 ± 4	27 ± 5
FEV_1, L	0.96 ± 0.29	1.23 ± 0.24
FEV_1, % pred	39 ± 12	45 ± 15
FVC, L	2.30 ± 0.96	2.94 ± 0.71
FVC, % pred	63 ± 23	74 ± 15
TLC, % pred	115 ± 25	127 ± 24
D_{LCO}, % pred	75 ± 15	68 ± 22
Pa_{O_2}, mm Hg	78 ± 9	77 ± 8
Pa_{CO_2}, mm Hg	43 ± 6	41 ± 4

* Values are mean ± SD.

TABLE 2

MEAN TRAINING INTENSITY AND DURATION ACHIEVED DURING TRAINING SESSIONS FOR THE 12-wk PROGRAM*

	Aerobic Training (*n = 15*)	Aerobic + Strength Training (*n = 21*)
Aerobic training		
Exercise session duration, min	26 ± 1	28 ± 1
Training intensity, watts	28 ± 9	38 ± 13[†]
Training intensity, % W max	73 ± 24	65 ± 13
Strength training		
Pectoralis major		
No. sets	—	2.8 ± 0.1
No. repetitions	—	10 ± 2
Workload, kg	—	28 ± 8
Workload, % 1 RM	—	81 ± 11
Latissimus dorsi		
No. sets	—	2.8 ± 0.1
No. repetitions	—	11 ± 1
Workload, kg	—	32 ± 7
Workload, % 1 RM	—	76 ± 11
Gluteus maximus		
No. sets	—	2.8 ± 0.1
No. repetitions	—	12 ± 2
Workload, kg	—	100 ± 27
Workload, % 1 RM	—	93 ± 14
Vastus lateralis		
No. sets	—	2.8 ± 0.1
No. repetitions	—	10 ± 2
Workload, kg	—	54 ± 12
Workload, % 1 RM	—	80 ± 8

* Values are mean ± SD and represent the amount of training, on average, at each training session for the entire program.
[†] $p < 0.05$ AERO + ST group versus AERO group.

TABLE 3

PHYSIOLOGIC PARAMETERS AT PEAK EXERCISE BEFORE AND AFTER AEROBIC TRAINING*

	Aerobic Training (n = 15)		Aerobic + Strength Training (n = 21)	
	Pretraining	Posttraining	Pretraining	Posttraining
$\dot{V}O_2$, L/min	0.91 ± 0.25	0.94 ± 0.25	1.13 ± 0.40	1.13 ± 0.41
$\dot{V}O_2$, % pred	56 ± 11	59 ± 20	66 ± 20	66 ± 22
Wmax, W	43 ± 18	51 ± 19	60 ± 23†	67 ± 29‡
Wmax, % pred	36 ± 12	44 ± 16	45 ± 16	51 ± 19‡
$\dot{V}E$, L/min	35.5 ± 10.5	35.4 ± 11.4	43.3 ± 15.9	42.1 ± 15.9
Heart rate, beats/min	124 ± 17	123 ± 19	132 ± 21	125 ± 21
Pa_{O_2}, mm Hg	70 ± 14	70 ± 14	66 ± 11	64 ± 13
Pa_{CO_2}, mm Hg	48 ± 8	48 ± 7	47 ± 7	48 ± 8
pH	7.35 ± 0.04	7.35 ± 0.03	7.35 ± 0.04	7.34 ± 0.05
Lactate, mmol/L	3.06 ± 1.32	3.20 ± 1.15	3.84 ± 1.23	3.62 ± 1.49

* Values are mean ± SD.
† $p < 0.05$ AERO + ST group versus AERO group at baseline.
‡ $p < 0.05$ pre- versus posttraining within each group.

heart rate (7%, $p < 0.05$), and arterial lactate concentration (17%, $p < 0.05$) for an identical exercise work rate were observed after training in the two groups (Table 4). After training, the functional exercise capacity also increased in both groups, as indicated by the improvement in the 6MWD, which increased from 388 ± 78 m to 454 ± 50 m in the AERO group and from 411 ± 81 m to 499 ± 68 m in the AERO + ST group ($p < 0.0005$). Health-related quality of life improved in both study groups (Table 5). For most dimensions of the CRQ, the effect size corresponded to a small (0.5-point) to moderate (1.0-point) improvement (23).

Comparisons between the Two Study Groups

The percent changes in bilateral thigh MCSA and in peripheral muscle strength before and after training are shown in Figure 1. As can be seen, the changes in thigh MCSA and in quadriceps and pectoralis major muscle strength were significantly greater in the AERO + ST group than in the AERO group ($p < 0.05$). In contrast, the magnitude of the changes in exercise capacity (Table 3), physiologic parameters at isoexercise (Table 4), 6MWD, and quality of life (Table 5) were comparable for the two groups.

DISCUSSION

This study sought to evaluate whether strength training is a useful addition to aerobic training in patients with COPD. We found that the combination of aerobic and strength training was safe and well tolerated despite the severity of the underlying lung disease, and was associated with greater improvement in peripheral muscle strength and in thigh MCSA than was aerobic training alone. However, these changes did not translate into further improvement in exercise tolerance or quality of life as measured in this study.

TABLE 4

PHYSIOLOGIC PARAMETERS AT ISOEXERCISE BEFORE AND AFTER AEROBIC TRAINING*

	Aerobic Training (n = 15)		Aerobic + Strength Training (n = 21)	
	Pretraining	Posttraining	Pretraining	Posttraining
$\dot{V}O_2$, L/min	0.89 ± 0.24	0.86 ± 0.25	1.13 ± 0.39	1.05 ± 0.31
Wmax, W	41 ± 17	41 ± 17	58 ± 23	58 ± 23
$\dot{V}E$, L/min	35.1 ± 10.4	31.9 ± 9.0†	42.8 ± 15.7	39.1 ± 13.7†
Heart rate, beats/min	123 ± 19	116 ± 20†	131 ± 21	120 ± 21†
Pa_{O_2}, mm Hg	68 ± 15	69 ± 13	69 ± 11	67 ± 12
Pa_{CO_2}, mm Hg	49 ± 9	47 ± 8	46 ± 8	46 ± 7
pH	7.34 ± 0.04	7.37 ± 0.05	7.35 ± 0.04	7.36 ± 0.04
Lactate, mmol/L	3.06 ± 1.32	2.62 ± 1.00†	3.66 ± 1.12	3.10 ± 1.43†

* Values are mean ± SD.
† $p < 0.05$ pre- versus posttraining within each group.

TABLE 5

MEAN DIFFERENCE IN HEALTH-RELATED QUALITY OF LIFE BEFORE AND AFTER TRAINING*

	Aerobic Training (n = 15)	Aerobic + Strength Training (n = 21)
Dyspnea	1.1 ± 0.8†	1.0 ± 0.8†
Fatigue	0.7 ± 0.6†	0.5 ± 0.9†
Emotion	0.4 ± 0.7†	0.4 ± 0.7
Mastery	1.0 ± 0.7†	0.4 ± 0.7†

* Values are mean ± SD.
† $p < 0.05$.

Effects on Strength Training Combined with Aerobic Training on Muscle Function

Together with the results of a previous study showing improved skeletal muscle oxidative capacity after exercise training in patients with moderate to severe COPD (24), the results of the present study confirm that such patients retain the capacity for improved peripheral muscle function with an adequate training stimulus. Furthermore, the magnitude of improvement in midthigh MCSA and peripheral muscle strength found in our study was similar to that reported in older normal subjects after a period of strength training (7). As compared with those of normal subjects of similar age studied in our laboratory, peripheral muscle strength and thigh MCSA in our COPD patients were not completely corrected after training (18), suggesting that the training period was not of sufficient duration or that factors other than chronic inactivity are involved in explaining muscle atrophy and weakness in patients with COPD.

In young and older normal subjects, muscle hypertrophy and improved neural recruitment patterns account for the increase in muscle strength following muscle training (7, 25, 26). Both mechanisms probably played a role in explaining the improvement in muscle strength after training in our patients. The increase in midthigh MCSA and the ability to demonstrate increased strength on an apparatus other than the training devices used in the study support the idea that structural adaptation to strength training took place in our patients. On the other hand, the occurrence of neural adaptation is suggested by the proportionally greater improvement in muscle strength than in muscle cross-sectional area.

Effects of Training on Exercise Capacity and Quality of Life

In accordance with the literature on pulmonary rehabilitation, both training modalities examined in the present study resulted in modest improvements in peak exercise capacity, whereas the change in functional exercise capacity (6MWD) was more pronounced (1). Most notably, significant reductions in heart rate, $\dot{V}E$, and blood lactate concentration for a given exercise work rate were found in both study groups, strongly suggesting that a physiologic training effect occurred. Despite the greater improvement in midthigh MCSA and muscle strength in the AERO + ST group, the changes in exercise capacity and in quality of life were of similar magnitude

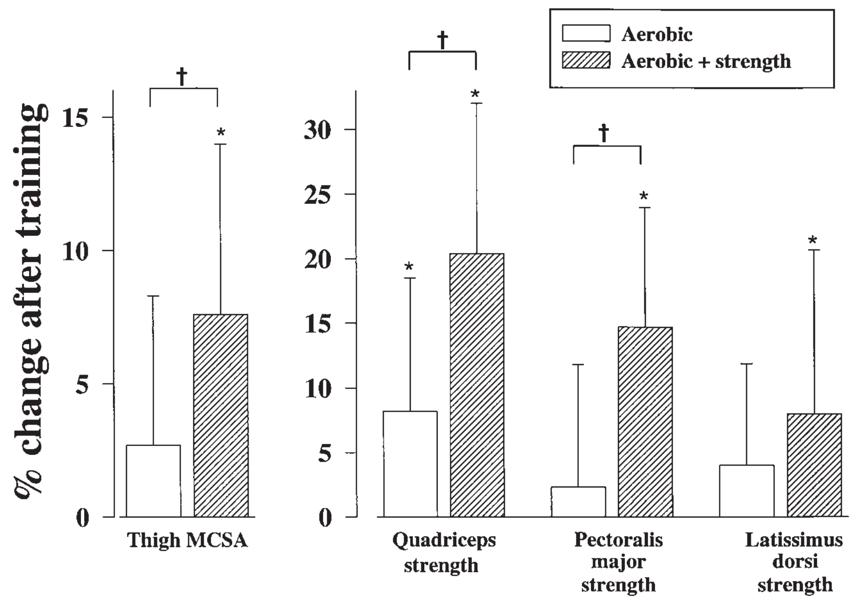

Figure 1. Mean ± SD percent change in bilateral thigh MCSA and in the strength of the quadriceps, pectoralis major, and latissimus dorsi muscles before and after training in the AERO and AERO + ST groups. The improvement in bilateral thigh MCSA and in the strength of the three muscle groups was statistically significant in the AERO + ST group. Quadriceps strength also showed a significant increase in the AERO group. As can be seen, the magnitude of the changes in thigh MCSA and in the strength of the quadriceps and pectoralis major muscles was significantly greater in the AERO + ST group than in the AERO group. (*$p < 0.05$ for pre- versus posttraining within each study group; $^{\dagger}p < 0.05$ for the AERO group versus the AERO + ST group.)

in the two study groups. However, it is possible that a longer duration of training would have produced a greater improvement in exercise capacity with the combination of strength and aerobic training than with aerobic training alone.

These results are remarkably similar to those previously reported in two studies of the effects of anabolic drugs and exercise training in patients with COPD (27, 28). In both cases the authors showed that the combined use of anabolic drugs and aerobic training produced a greater improvement in peripheral muscle mass and strength than did exercise training alone. However, no further gain in exercise tolerance was obtained with the combination of anabolic drugs and exercise training. Perhaps the changes in peripheral muscle function in our study and these other studies were not of sufficient magnitude to further improve exercise capacity. Another possible explanation for the dissociation between changes in muscle mass and strength and exercise capacity is the relative task specificity of any training stimulus: the greatest improvement in muscle function is shown in tests that closely mimic the characteristics of the training movement (7). An important implication of this observation is that the training movements should resemble activities that are relevant to the patient's daily activities. Further studies will be needed to determine whether greater improvement in peripheral muscle function can enhance exercise capacity, and whether these muscle changes can be translated into greater ease in performing activities of daily living.

Role of Strength Training in Exercise Training Programs in Patients with COPD

Although we could not exclude the possibility that prolonging the duration of leg cycling exercises would have had the same beneficial effects on peripheral muscle function as the combination of strength training and aerobic training, we found that strength training has several interesting features that could help patients with severe COPD. We found, as did Simpson and colleagues, that the muscle resistive exercises induced less dyspnea than did the cycling exercise, and as a result were well tolerated by the patients (6). The implementation of muscle resistive exercises also helped diversify the training sessions and maintain the patients' interest and motivation during the training program. In addition to its beneficial effects on peripheral muscle function, strength training may help increase bone density (29), a potentially interesting effect for patients with COPD, in whom osteoporosis is highly prevalent (30). Strength training should be used cautiously in patients with musculoskeletal disorders and/or osteoporosis, in order to avoid injury such as bone fracture. However, when adapted to the individual patient's condition, we found that intense muscle exercises could be performed safely in patients with COPD.

Criticisms of the Study

The improvement in peak exercise work rate was of similar magnitude for the two groups investigated in our study. However, the change in peak exercise work rate reached statistical significance only in the AERO + ST group; this was probably due to a type II error, since fewer patients were included in the AERO group. It is unlikely that including more patients in the study would have changed the conclusion that the improvements in peak exercise capacity and 6MWD were similar for the two study groups. Using the baseline peak exercise work rate values, we calculated that more than 1,000 patients per group would have been required to show that the observed pre- to posttraining improvements in maximal exercise capacity were statistically different for the two study groups. A study of this size would not only be difficult to conduct, but its results would also be of no clinical significance. Because of practical considerations (*see* METHODS), patients in the fourth block were allocated to the same training modality (AERO + ST). Although this may have influenced our results, we believe that any potential biases were minimized, since: (*1*) the training modality used for the patients in the fourth block was selected in a random fashion; and (*2*) the characteristics of the patients in the first three blocks and those in the fourth block were similar.

In summary, the addition of strength training in aerobic training was safe and well tolerated in patients with severe COPD, and was accompanied by greater improvement in muscle mass and strength then was aerobic training alone. This study therefore confirms that the peripheral muscles may show structural adaptation with an appropriate training regimen despite severe ventilatory impairment. This observation is important, given the potentially adverse effects of peripheral muscle dysfunction on exercise tolerance and quality of life in patients with COPD. However, further studies are required to clarify the extent to which any improved peripheral muscle function that could be obtained with exercise training might improve exercise tolerance in patients with COPD.

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