

Endurance and Strength Training in Patients With COPD*

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Study objectives: The purpose of this study was to compare the effects of endurance training only to endurance plus strength (combined) training in a randomized trial of patients with COPD.

Methods: Twenty-four patients completed the study: 11 patients in the combined training group (FEV₁ 45 ± 5% predicted), and 13 patients in the endurance training group (FEV₁ 40 ± 4% predicted) [mean ± SE]. Muscle strength, quality of life, exercise performance, and quadriceps fatigability were measured before and after rehabilitation.

Results: Combined training led to significant improvements in quadriceps (23.6%), hamstring (26.7%), pectoralis major (17.5%), and latissimus dorsi (20%) muscle strength. Endurance training alone did not produce significant improvements in muscle strength: quadriceps (1.1% decrease), hamstring (12.2% increase), pectoralis major (7.8% increase), and latissimus dorsi (2.8% decrease). The increase in strength after training was significantly greater in the combined group compared to the endurance group for the quadriceps and latissimus dorsi muscles but not for the hamstring and pectoralis major muscles. Six-minute walk distance, endurance exercise time, and quality of life (as measured by the Chronic Respiratory Questionnaire) significantly increased in both groups after rehabilitation with no significant differences in the extent of improvement between groups. The extent of improvement in quadriceps fatigability after training (assessed by quadriceps twitch force before and after exercise) was not significantly different between groups.

Conclusion: Strength training can lead to significant improvement in muscle strength in elderly patients with COPD. However, this improvement in muscle strength does not translate into additional improvement in quality of life, exercise performance or quadriceps fatigability compared to that achieved by endurance exercise alone. (CHEST 2004; 125:2036–2045)

Key words: exercise; exercise therapy; muscles, skeletal; pulmonary disease, chronic obstructive; rehabilitation

Abbreviations: CRQ = Chronic Respiratory Questionnaire; TwQp = potentiated twitch; TwQu = unpotentiated twitch; Wmax = maximal work capacity

Patients with advanced COPD have impaired exercise tolerance that limits their activities of daily living. Peripheral muscle atrophy and weakness are common in patients with COPD and are associated with reduced exercise capacity.^{1–3} If peripheral muscle weakness is responsible for the reduced exercise capacity, then one would expect that increases in

muscle strength would lead to improvements in exercise performance. Several studies^{4,5} have examined the effects of weight training alone in patients with COPD. Weight training in patients with COPD has resulted in increases in muscle strength and size.^{4–6} In addition, weight training significantly improved performance of whole-body endurance exercise.^{4,5}

Traditional pulmonary rehabilitation focuses primarily on aerobic endurance training.⁷ Endurance training in patients with COPD consistently leads to clinically significant improvement in submaximal exercise performance with variable effects on maximal exercise capacity.^{8,9} While some of this improvement may be related to psychological factors, there is increasing evidence that endurance training results in physiologic changes within the exercising muscle. Improvements in oxidative enzyme capacity,¹⁰ cellular bioenergetics,¹¹ and a reduction in fatigability¹² have all been demonstrated in the quadriceps muscle

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in patients with COPD after pulmonary rehabilitation. The question arises as to whether the addition of strength training to an endurance exercise program would provide additional benefits to that achieved by endurance training alone. In a prior carefully performed study, Bernard and colleagues⁶ addressed this issue. Disappointingly, although strength training was effective at making the muscles stronger, this increase in strength did not translate into additional improvements in exercise performance or quality of life from that observed following endurance training only. Because this is such an important issue, we believed it deserved additional investigation. Accordingly, the purpose of this study was to compare the effects of endurance training only to endurance plus strength (combined) training in a randomized trial of patients with COPD. The patients in our rehabilitation program historically are generally a little older and weaker than those in the study by Bernard and colleagues,⁶ and so might be particularly amenable to strength training. We hypothesized that in this patient population, the addition of strength training might provide additional improvement in quality of life and exercise performance to that achieved by endurance exercise alone. Our strength training program focused not only on the upper leg muscles but also on the chest and upper arm muscles, since these muscles may have some ventilatory actions and strengthening these muscles might reduce dyspnea during exercise, thus potentially improving exercise performance and quality of life.¹³

MATERIALS AND METHODS

Subjects

Thirty-two consecutive patients with COPD who entered our pulmonary rehabilitation program agreed to participate in the study. None of the patients had ever participated in a rehabilitation program. Patients were grouped into classes of three to five patients. Each class was randomly assigned (opaque sealed envelope) to endurance training alone or combined training. Seventeen patients were randomized to the endurance group, and 15 patients were randomized to the combined group. Four patients in each group either failed to complete the rehabilitation program ($n = 2$ in each group) or refused postrehabilitation measurements ($n = 2$ in each group). Thus, there were 13 patients in the endurance group and 11 patients in the combined group. The study was approved by the appropriate institutional review boards, and written informed consent was obtained from all subjects.

The diagnosis of COPD was made by a clinical course consistent with chronic bronchitis and/or emphysema, a long history of cigarette smoking (70.0 ± 7.3 pack years), and pulmonary function test findings revealing irreversible airflow obstruction. All 24 patients who completed the study were receiving inhaled β -agonists, 19 were receiving inhaled anticholinergics, 17 were receiving inhaled steroids, and 4 were receiving oral theophylline.

One patient in the strength group was on oral prednisone. Two patients were receiving continuous supplemental oxygen ($n = 1$ in each group), and four patients were prescribed supplemental oxygen with exertion ($n = 2$ in each group). To be eligible for our pulmonary rehabilitation program, patients had to have successfully quit smoking for at least 3 months prior to assessment.

Exercise Training

Endurance Training: Patients underwent supervised exercise sessions, three times a week for 8 weeks. On the cycle ergometer, patients initially exercised at 50% of the maximal work capacity [W_{max}] achieved during the maximal incremental exercise test. When the patients could exercise for 20 min without intolerable dyspnea (defined as a Borg rating of breathlessness of ≤ 5 during exercise), the workload was increased by 10%. Treadmill exercise was started at a speed ranging from 1.1 to 2.0 miles per hour, 0% elevation based on the patient's functional capacity (6-min walk results). When the patients could exercise for 15 min without intolerable dyspnea (Borg rating of breathlessness of ≤ 5), the speed and/or elevation was increased. The patients had a brief warm-up and cool down after each exercise bout. At the beginning of each session, a series of stretching exercises was performed. In a prior study using an identical training regimen (same frequency, intensity, duration, and progression), we found significant improvements in maximal and endurance exercise performance.¹² In our usual rehabilitation program, the patients perform a series of calisthenics with and without small weights. These exercises were not included to ensure that the endurance group received only endurance training. The patients also received weekly 1-h educational classes consisting of informal small group discussions on topics believed to be relevant in the rehabilitation of patients with COPD.

Strength Training: The strength group performed four different strength exercises in addition to endurance training. Knee flexion involving predominantly the hamstring muscles, knee extension involving predominantly the quadriceps muscle, seated chest press involving predominantly pectoralis major, and a combined movement of shoulder adduction and elbow flexion primarily involving latissimus dorsi.⁶ Patients were initially asked to perform one set of 10 repetitions at 60% of their one repetition maximum. This was gradually increased to three sets of 10 repetitions. When the patients could perform three sets without undue difficulty, the weight was increased by 5 lb.

Therefore, one group of patients received endurance exercise training plus education (the endurance group), and the other group received education, endurance, and strength training (the combined group). Compliance during the rehabilitation program was excellent $> 90\%$. Any sessions missed were made up at the end of the 8-week program to ensure that all subjects completed the 24 sessions of the rehabilitation program.

Pulmonary Function, Exercise Testing, and Quality of Life

Spirometry was performed according to American Thoracic Society recommendations.¹⁴ Lung volumes were measured by body plethysmography and single-breath diffusing capacity was also measured. Predicted normal values were those of Crapo et al.¹⁵⁻¹⁷ The technicians were blinded to the subject's group. Maximal inspiratory pressure was measured with a differential pressure transducer (Model MP-45 \pm 350 cm H₂O; Validyne Corporation; Northridge, CA) while performing a maximal inspiratory effort against an occluded airway near residual volume. Pulmonary function is shown in Table 1. Pulmonary function testing was repeated after rehabilitation was completed.

Table 1—Patient Characteristics*

Characteristics	Endurance Training (n = 13)	Combined Training (n = 11)
Age, yr	68 ± 2	74 ± 2†
Height, m	1.75 ± 0.02	1.75 ± 0.02
Weight, kg	85 ± 7	85 ± 2
Body mass index	27.5 ± 2.0	27.6 ± 0.4
FEV ₁ , L	1.34 ± 0.13	1.43 ± 0.16
FEV ₁ , % predicted	40 ± 4	44 ± 4
FVC, L	2.59 ± 0.17	2.55 ± 0.18
FVC, % predicted	60 ± 5	60 ± 4
Total lung capacity, % predicted	103 ± 5	105 ± 6
Residual volume, % predicted	167 ± 18	175 ± 18
DLCO, % predicted	61 ± 7	64 ± 8
Maximum voluntary ventilation, L/min	50.9 ± 5.0	54.2 ± 5.9
Maximum inspiratory pressure, cm H ₂ O	60.0 ± 4.2	67.0 ± 11.2

*Data are presented as mean ± SE. DLCO = diffusing capacity of the lung for carbon monoxide.

†Significant difference between groups.

An incremental symptom-limited exercise test was performed to determine each subject's Wmax. After a 3-min acclimatization period and 1 min of pedaling at 0 W, the workload was increased by 10 W every minute until the subject could no longer continue. The last workload for which a subject was able to complete 30 s of cycling was designated Wmax.

Several days after the incremental exercise test, constant workload (endurance test) exercise was performed on an electronically braked cycle ergometer at 60% of Wmax to volitional exhaustion. The subjects were allowed 3 min to acclimatize to the breathing circuit; they then exercised for 1 min at 0 W and 2 min at 10 W (warm-up period) before initiating exercise at 60% of Wmax. Expired gas was analyzed for oxygen and carbon dioxide by a zirconium electrochemical cell oxygen analyzer and an infrared carbon dioxide analyzer, respectively. Flow was measured with a pneumotachograph (preVent Pneumotach; Medgraphics; St. Paul, MN). A microprocessor calculated breath-by-breath values of oxygen uptake, carbon dioxide production, minute ventilation, and its components (respiratory rate and tidal volume), and the results were averaged every 30 s. The patients who were receiving oxygen during exercise breathed from a 200-L reservoir bag containing 35% oxygen.

After pulmonary rehabilitation was complete, three exercise tests were performed on separate days. On the first day, the maximal exercise test was repeated. Isowork comparisons were made at the highest workload reached both before and after rehabilitation. On the second day, the endurance test was repeated (at 60% of the pretraining Wmax), and the test was stopped by the investigator when the prerehabilitation endurance time was reached (for quadriceps measurements). On the final day, the endurance test was repeated but the patient was allowed to continue exercising to the limits of tolerance (to evaluate any potential improvement in exercise endurance). Isotime comparisons were made at the farthest time reached both before and after rehabilitation.

Six-minute walk tests were administered before (the best of three tests) and after completion of the rehabilitation program (the best of three tests) as an additional test of functional capacity. Subjects were given standardized instructions to cover the greatest distance possible in 6 min. Standardized verbal encouragement was given each minute. The nurse supervising the walks was blinded to the subject group.

Health-related quality of life was measured with the Chronic Respiratory Questionnaire (CRQ), which was administered by a trained interviewer.¹⁵ The subjects were shown their previous

scores during postrehabilitation measurements. The interviewer was blinded to the subject's group.

Muscle Measurements

Measurement of quadriceps, hamstring, pectoralis major, and latissimus dorsi muscle strength was made during dynamic contractions against hydraulic resistance (HF STAR; Henley Health Care; Belton, TX).¹ After familiarization with the technique, two sets of three contractions each were obtained for each muscle group at the highest resistance level, level 6. The highest value for peak force was reported.

Quadriceps fatigability was assessed by measuring quadriceps twitch force during supramaximal magnetic stimulation of the femoral nerve¹⁹ before and after endurance cycle exercise. Quadriceps twitch force was measured as previously described.^{12,20,21} In many of the patients, magnetic stimulation of the femoral nerve elicited a large shock artifact that obscured the compound motor action potential (M-wave). However, with careful positioning of the surface electrodes and ground, M-waves were obtained before rehabilitation in 15 patients and after rehabilitation in 13 patients. Following a vigorous voluntary contraction, the subsequent twitch is significantly increased in size (twitch potentiation).²² Studies^{23–24} have suggested that the potentiated twitch (TwQp) is more sensitive at detecting fatigue than the unpotentiated twitch (TwQu), particularly when the amount of fatigue is small. Accordingly, we measured both TwQu and TwQp before and 10 min, 30 min, and 60 min after exercise. TwQu and TwQp were measured as previously described.^{12,20,21} To determine the degree to which our subjects could voluntarily activate their quadriceps muscle, twitch interpolation was employed during maximum voluntary contraction maneuvers as previously described.^{12,21}

Data Analysis

Data are expressed as the mean ± SE. Changes in variables over time and between groups were analyzed by repeated-measures analysis of variance. Differences between groups were analyzed by comparing both the absolute and percentage differences between the pretraining and posttraining values. The results of these two analyses were congruent in all cases. The p values expressed represent the values obtained by comparing the absolute differences. Baseline values for the two groups were compared by unpaired *t* test.

RESULTS

Baseline characteristics of the 24 patients who completed the protocol are shown in Table 1. Patients had moderate-to-severe airflow obstruction with air trapping. The pulmonary function of the two groups was well matched, with no significant difference for any pulmonary function variable between groups. The combined group was slightly older than the endurance group. As expected pulmonary function was unchanged after pulmonary rehabilitation (data not shown).

Training Sessions

Every subject completed 24 sessions of training. The average duration of cycle and treadmill exercise during each session was similar in both groups. The weekly change in treadmill speed and cycle workload was compared between groups by repeated-measures analysis of variance. The rate of progression of cycle and treadmill exercise was similar in the two groups.

Effect of Training on Muscle Strength

In the endurance group, quadriceps (1.1% decrease, $p > 0.8$), hamstring (12.2% increase, $p < 0.10$), pectoralis major (7.8% increase, $p > 0.2$), and latissimus dorsi (2.8% decrease, $p > 0.8$) strength were not significantly different after training (Table 2). In the combined group, quadriceps (23.6% increase, $p < 0.005$), hamstrings (26.7% increase, $p < 0.03$), pectoralis major (17.5% increase, $p < 0.03$), and latissimus dorsi (20% increase, $p < 0.04$) strength all were significantly increased after training (Table 2). Strength at baseline for the two groups was not significantly

different for any of the four muscles. The increase in strength after training for the combined group was significantly larger than that achieved in the endurance group for the quadriceps ($p < 0.002$) and latissimus dorsi ($p < 0.03$) muscles, but this difference was not statistically significant for the hamstrings ($p < 0.20$) and pectoralis major ($p = 0.20$) muscles.

Effect of Training on Quality of Life

There were no differences at baseline in any of the quality-of-life domains between the two groups (Table 2). Both groups had statistically and clinically significant improvement in the dyspnea and fatigue domains after rehabilitation but there was no difference in the extent of improvement between groups. The minimal clinically significant difference is defined as a mean improvement of 0.5 per question.²⁵ The extent of improvement in the dyspnea score after training was 0.5 (per question) larger in the endurance only group compared to the combined group (95% confidence limits, -0.1 to 1.1). The extent of improvement in the fatigue score after training was 0.15 larger in the endurance-only group compared to the combined group (95% confidence limits, -0.5 to 0.8). Small improvements in the emotion domain were observed in both groups, which reached statistical but not clinical significance in the combined group.

Effect of Training on Exercise Performance

At baseline, maximal exercise parameters were not significantly different between groups (Table 3). Maximal exercise capacity did not significantly improve in either group after rehabilitation. At the

Table 2—Strength and Quality-of-Life Measurements*

Variables	Endurance		Combined	
	Before Rehabilitation	After Rehabilitation	Before Rehabilitation	After Rehabilitation
Quadriceps, kg	46 ± 3	45 ± 3.3	46 ± 5	55 ± 6†‡
Hamstrings	31 ± 2	34 ± 2	31 ± 5	37 ± 5†
Pectoralis major	46 ± 4	48 ± 3	42 ± 5	47 ± 4†
Latissimus dorsi	41 ± 3	40 ± 4	35 ± 4	40 ± 4†‡
Dyspnea	3.5 ± 0.2	4.7 ± 0.2†	3.6 ± 0.3	4.2 ± 0.3†
Fatigue	3.6 ± 0.3	4.5 ± 0.3†	4.1 ± 0.4	4.7 ± 0.4†
Emotion	5.4 ± 0.3	5.6 ± 0.3	4.8 ± 0.3	5.0 ± 0.3†
Mastery	5.6 ± 0.3	5.7 ± 0.2	5.0 ± 0.5	5.2 ± 0.5

*Data are expressed as mean ± SE.

†Significant difference from before rehabilitation.

‡Significant difference in extent of improvement after rehabilitation between the endurance and combined groups. There were no differences in strength for any muscle group at baseline between the two groups. Strength improved significantly after pulmonary rehabilitation in all muscle groups tested in the combined group. Strength improved to a greater extent in the combined group compared with the endurance group for the quadriceps and latissimus dorsi muscles. There were no differences in quality of life at baseline between the two groups. Both groups had statistically and clinically significant improvement in the dyspnea and fatigue domains after rehabilitation, but there was no difference in the extent of improvement between groups.

Table 3—Maximal Exercise Data*

Variables	Endurance			Combined		
	Before Rehabilitation	After Rehabilitation After Exercise	After Rehabilitation Isowork	Before Rehabilitation	After Rehabilitation After Exercise	After Rehabilitation Isowork
Workload, W	49 ± 9	54 ± 8		55 ± 9	63 ± 9	
$\dot{V}O_2$, L/min	1.03 ± 0.08	1.16 ± 0.11	0.98 ± 0.07	0.94 ± 0.12	1.06 ± 0.13	1.00 ± 0.14
$\dot{V}E$, L/min	42.6 ± 3.8	42.7 ± 4.2	38.2 ± 3.6†	44.2 ± 3.3	49.7 ± 5.5†	45.4 ± 5.4
HR, beats/min	118 ± 5	117 ± 6	113 ± 6	122 ± 8	117 ± 5	115 ± 5

*Data are presented as mean ± SE. $\dot{V}O_2$ = oxygen consumption; $\dot{V}E$ = minute ventilation; HR = heart rate.

†Significant difference from prerehabilitation value. Maximal exercise performance was not significantly improved after rehabilitation in either group. There were no significant differences in the prerehabilitation measurements between groups.

same work rate, heart rate decreased by 4% and 6%, respectively, after rehabilitation, but this modest decrease did not reach statistical significance in either group. At the same work rate, minute ventilation was significantly decreased in the endurance group but not in the combined group.

At baseline, no significant difference in endurance exercise parameters were observed between groups (Table 4). Endurance exercise time increased significantly in both groups, but there was no significant difference in the extent of improvement between groups. The extent of improvement in the endurance exercise time after training was 0.3 min larger in the combined group compared to the endurance only group (95% confidence limits, -7.5 to 8.1 min; p = not significant). At exercise isotime, minute ventilation and heart rate were significantly decreased after rehabilitation with no significant difference between groups.

At baseline, there was no significant difference in 6-min walk distance. Six-minute walk distance significantly increased in both groups after training (1,274 ± 106 to 1,360 ± 106 feet in the endurance group, and 1,235 ± 115 to 1,345 ± 124 feet in the combined group) with no significant difference be-

tween groups. The extent of improvement in the 6-min walk after training was 24 feet larger in the combined group compared to the endurance only group (95% confidence limits, -51 to 99 feet; p = not significant). The average improvement in both groups was < 54 m (177 feet), which is the minimal detectable difference noticeable by patients when they compare themselves to others.²⁶

Effect of Training on Quadriceps Fatigability

TwQu and TwQp before and after exercise, before and after rehabilitation are shown in Figure 1, *top*, for the endurance group, and Figure 1, *bottom*, for the combined group. For the endurance group, TwQu fell modestly after exercise before training; while the fall in TwQu was slightly less after training, this difference was not statistically significant. For the combined group, TwQu fell modestly after exercise before training. After training, TwQu fell at least as much as it did before training. The fall in TwQu after exercise was similar in the two groups before training. The change in the extent of fall in TwQu with training was not significantly different for the two groups.

Table 4—Endurance Exercise*

Variables	Endurance			Combined		
	Before Rehabilitation	After Rehabilitation After Exercise	After Rehabilitation Isotime	Before Rehabilitation	After Rehabilitation After Exercise	After Rehabilitation Isotime
Endurance time, min	8.8 ± 1.6	20.8 ± 3.4†		9.3 ± 1.7	21.6 ± 2.1†	
$\dot{V}O_2$, L/min	1.05 ± 0.09	0.97 ± 0.09	0.92 ± 0.07	0.93 ± 0.11	0.98 ± 0.08	0.87 ± 0.08
HR, beats/min	118 ± 5	111 ± 5	108 ± 4†	120 ± 8	111 ± 4	107 ± 5†
$\dot{V}E$, L/min	39.6 ± 3.4	37.6 ± 3.4	35.4 ± 3.3†	43.9 ± 4.3	43.1 ± 3.9	39.4 ± 3.3†
V_T , L	1.35 ± 0.08	1.34 ± 0.08	1.31 ± 0.09	1.31 ± 0.11	1.33 ± 0.11	1.28 ± 0.10
F, breaths/min	30.2 ± 1.9	30.3 ± 1.7	28.2 ± 2.1	34.2 ± 2.3	35.2 ± 2.1	31.8 ± 2.1†

*Data are presented as mean ± SE. See Table 3 for expansion of abbreviations. V_T = tidal volume; F = respiratory rate.

†Significant difference from before rehabilitation value. Both groups had a significant improvement in exercise endurance time with training, but there was no difference in the extent of improvement between groups. There was a significant reduction in heart rate and minute ventilation at exercise isotime after rehabilitation, with no significant difference in the extent of the response between groups. There were no significant differences in the prerehabilitation measurements between groups.

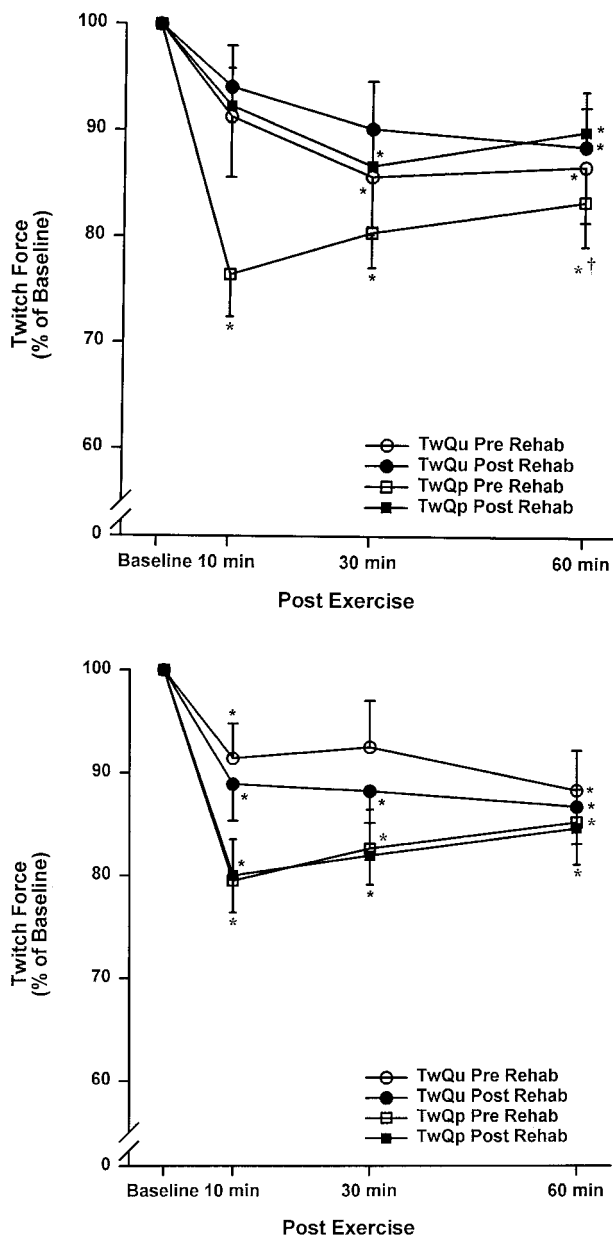


FIGURE 1. TwQu and TwQp expressed as a percentage of baseline before and 10 min, 30 min, and 60 min after exercise before rehabilitation (Pre Rehab) and after rehabilitation (Post Rehab) in the endurance group (*top*) and the combined group (*bottom*). *Significant difference from baseline. †Significant difference from postrehabilitation value. The fall in TwQu after exercise was not significantly different after rehabilitation compared to before rehabilitation in either group. The fall in TwQp after exercise was not significantly different after rehabilitation compared to prerehabilitation in the combined group. The fall in TwQp after exercise was significantly less after rehabilitation compared to before rehabilitation in the endurance group. The difference between groups, however, was not significantly different.

TwQp before and after exercise, before and after rehabilitation is shown in Figure 1, *top*, for the endurance group and Figure 1, *bottom*, for the combined group. In the endurance group, TwQp fell

significantly after exercise before training to a minimum of $76.4 \pm 4.0\%$ of the baseline value at 10 min after exercise. TwQp also fell significantly after exercise after training, but the fall in TwQp was significantly less after training. In the combined group, TwQp fell significantly after exercise before training to a minimum value of $79.5 \pm 3.1\%$ of the baseline value at 10 min after exercise. TwQp fell to a similar extent after exercise after training. Before training, the fall in TwQp after exercise was similar in the two groups. The change in the extent of fall in TwQp with training was also not significantly different for the two groups. In the subjects in whom reliable compound motor action potentials (M-waves) could be obtained, there was no change in M-wave amplitude at any time after exercise either before or after training.

Superimposed twitches averaged $7.2 \pm 3.6\%$ of TwQp at baseline before rehabilitation in the combined group and $6.8 \pm 2.6\%$ in the endurance group. There was no significant change in the superimposed twitch after exercise either before or after rehabilitation in either group. There were no significant differences in the superimposed twitch between groups or before and after rehabilitation in either group. TwQp at baseline (before exercise) significantly increased after training in the combined group (9.6 ± 1.1 to 11.1 ± 1.6 kg) but not the endurance group (10.7 ± 0.4 to 10.7 ± 0.5 kg), providing an effort independent verification that quadriceps strength did in fact increase after strength training.

DISCUSSION

The major findings of this study were as follows: (1) addition of strength training to an endurance exercise program led to improvements in muscle strength in patients with COPD, and (2) this improvement in muscle strength did not translate into additional improvement in endurance exercise performance or quality of life compared to that achieved by an endurance exercise program alone.

Effects of Strength Training on Muscle Strength and Performance of Rehabilitation

In this study, a relatively simple strength training program was successful in increasing strength in all muscles that underwent training. The extent of improvement was similar to that achieved in a prior study⁶ of patients with COPD, and also to that achieved in elderly healthy subjects.²⁷ In healthy subjects, improvements in muscle strength after strength training are due to both muscle hypertrophy and improved neural recruitment patterns.^{27,28} In a prior study,⁶ a similar training protocol led to docu-

mented muscle hypertrophy as measured by CT scan. However, the increase in strength exceeded the increase in muscle size, indicating that improved neural recruitment patterns^{27,28} were also operative. In our study, we did not measure muscle cross-sectional area, so we cannot say whether muscle hypertrophy occurred.

Our patients were elderly, and none of the patients performed any type of regular exercise prior to entering the rehabilitation program. A potential concern in this patient population would be that strength training would tire the patient and inhibit performance of concurrent endurance exercise. However, our strength group performed the same amount of endurance exercise per session as the endurance group. Furthermore, the rate at which the cycle workload and treadmill speed was increased during the rehabilitation sessions was not significantly different between groups. Thus, there was no evidence that strength training interfered in any way with endurance training. Strength training was well tolerated, and no injuries occurred during training.

Our patients were slightly older in the combined training group. Theoretically, age could have blunted the response to exercise. However, in retrospectively reviewing all patients who have entered our pulmonary rehabilitation program, we have not found age to be a significant predictor of the response to exercise training in patients with COPD, so this explanation appears unlikely although it cannot be entirely excluded.

Effect of Strength Training on Exercise Performance and Quality of Life

Exercise capacity has been shown to correlate with muscle strength independent of lung function in patients with COPD.¹⁻³ If muscle strength was causally responsible for the reduction in exercise capacity then improvement in muscle strength should result in improvement in exercise performance. Weight training in patients with COPD has been shown to improve exercise performance^{4,5} and quality of life⁴ compared to a control group. However, when we added strength training to an endurance exercise program no additional increment in exercise performance or quality of life was noted beyond that achieved by endurance training alone. Similar results were observed in a prior study,⁶ in which peak exercise capacity and 6-min walk distance were obtained. In our study, we also measured submaximal constant-workload exercise, which might be a more sensitive measure of change in endurance capacity,⁹ but were unable to appreciate any difference between the two groups. Further study using a greater number of participants would be required to

absolutely exclude an additive effect of strength training on exercise performance, but the results of our study as well as previous studies would not lend support to such an endeavor.

Of interest, the addition of anabolic hormones to an endurance training program has resulted in an increase in muscle strength and mass with no additional improvement in exercise performance.^{29,30} These results suggest that either muscle strength *per se* does not directly influence exercise performance, or that the improvement in muscle strength was not large enough to result in an improvement in exercise performance. However, practically the changes in muscle strength were not trivial. More aggressive strength training regimens have been employed in younger subjects (higher intensity, lower number of repetitions per set) and are believed to produce greater increases in muscle strength but such a regimen is not recommended in older subjects by the American College of Sports Medicine because of the increased risk of orthopedic injury.³¹

Muscle strength may be a surrogate marker for other muscle properties such as endurance, which may influence exercise performance more directly, particularly submaximal exercise. Quadriceps endurance can be measured,³² although the variability of such measurements in patients with COPD needs to be better defined. It would be of interest to see if measures of quadriceps endurance also predict exercise capacity, and whether improvements in quadriceps endurance after training would correlate with improvement in exercise capacity.

There is task specificity to any training stimulus. The greatest improvements in muscle function are observed with tasks that most closely resemble the training stimulus.²⁸ Weight training is clearly very different than stationary cycling or walking. Submaximal exercise should be primarily influenced by the endurance properties of the muscle that may be little affected by strength training.

Strength training did not produce any additional improvement in quality of life as measured by the CRQ. It is, however, possible that some activities of daily living might be improved by strength training. Such activities, particularly if they are not performed frequently, might not be of sufficient impact to significantly alter the CRQ score, particularly the dyspnea score, since this domain by design focuses on dyspnea during five activities that the patient deems are most important during day-to-day life. A more comprehensive functional assessment might elicit subtle changes that could be missed by the CRQ. The clinical significance of such changes (if they occurred) would need to be determined. In addition, two studies^{33,34} have compared the effects of strength training to endurance training in patients

with COPD. In both studies, quality of life as measured by the CRQ improved with either endurance or strength training with no significant difference between groups in the extent of improvement, despite differences between groups in improvements in muscle strength and submaximal endurance exercise. It appears that almost any exercise program results in improved quality of life in patients with COPD, but there may be a ceiling effect beyond which the unchanged pulmonary mechanics limits any further improvement.

In the elegant study by Ortega and colleagues,³⁴ the authors compared strength training alone, endurance training alone, and combined therapy in patients with COPD. In the combined therapy group, the amount of resistance and endurance training was reduced by 50%, so that the total time spent exercising would be equivalent for the three groups. The endurance and combined groups had greater improvement in exercise performance than the strength group, while the strength and combined groups had greater improvements in muscle strength than the endurance only group. The authors interpreted their results as indicating that combined therapy was the best therapy to offer patients with COPD since it produced improvements in both muscle strength and exercise performance. Improvement in muscle strength is usually considered desirable since it can be associated with improvements in body composition, bone mineral density, favorable neurohumeral changes, and functional status.³¹ However, whether similar benefits can be achieved in patients with COPD remains to be determined.

In the study by Ortega and colleagues,³⁴ the improvement in maximal exercise performance and submaximal endurance time appeared to be less in the combined group compared to the endurance-only group, although these differences were not statistically significant. In our study, we had patients perform the same amount of endurance exercise in the combined group as was performed in the endurance-only group. The patients had no difficulties achieving this goal, and the improvement in exercise performance was very similar in both groups. Thus, if strength training is added to a rehabilitation program, our results would suggest that adjustment of the endurance training regimen is not required.

Effect of Strength Training on Muscle Fatigability

We found that addition of strength to endurance training did not make the quadriceps less fatigable beyond that achieved by endurance training alone. Strength training was successful at increasing muscle strength, but this increase in strength did not trans-

late into decreased fatigability during cycle exercise. In a prior study¹² in which we observed both increased quadriceps strength and decreased quadriceps fatigability after endurance training in patients with COPD, we found no correlation between the increase in strength and the decreased fatigability, again suggesting that modest improvements in quadriceps muscle strength will not lead to improved fatigue resistance of the quadriceps muscle during whole-body exercise.

Comparison of Results to Those Obtained in Normal Subjects

There is a substantial body of literature evaluating the effects of combined strength and endurance training compared to single modality training in normal subjects. Addition of endurance training to strength training has impaired the improvement in strength in some studies,³⁵⁻³⁹ but not in others.⁴⁰⁻⁴⁴ One factor that may be important is the frequency of training.⁴⁵ When training is restricted to 3 d/wk as it was in our study, similar increases in strength are observed in strength and combined training groups.⁴⁰⁻⁴⁴ When training occurs 5 to 6 d/wk, combined training often leads to a smaller improvement in some strength performance measures compared to strength training alone.^{35-38,46,47} Ortega and colleagues³⁴ found no difference in the extent of improvement in strength following combined training compared to strength training alone in patients with COPD exercising three times a week.

In contrast, addition of strength training to an endurance exercise program has not impaired the response to endurance training in the vast majority of studies,^{35,37-39,42,43,46,47} although there is at least one conflicting report.⁴⁸ In some studies, addition of strength to endurance training has actually increased some measures (aerobic enzyme capacity,⁴³ muscle capillarization³⁵) that might influence muscle endurance. In our study, we found no difference in endurance or maximal exercise performance between groups suggesting that strength training neither enhanced nor inhibited the response to endurance training.

In conclusion, strength training when added to an endurance exercise program can produce significant improvements in muscle strength in elderly patients with COPD that are not seen with endurance training alone. However, improvement in muscle strength does not translate into additional improvement in quality of life, maximal exercise capacity, or endurance exercise performance from that achieved by an endurance exercise program alone. Strength training appears to be well tolerated in patients with COPD and whether it has favorable

effects on other potentially important outcomes will need to be determined in future studies.

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