Exercise in chronic pulmonary disease: resistance exercise prescription

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ABSTRACT

STORER, T. W. Exercise in chronic pulmonary disease: resistance exercise prescription. *Med. Sci. Sports Exerc.*, Vol. 33, No. 7, Suppl., pp. S680–S686, 2001. Resistance exercise training has received relatively little attention as a means to reduce the muscle dysfunction and ensuing exercise intolerance seen in chronic pulmonary diseases. To date, only a few studies have examined the characteristics of skeletal muscle function or its responsiveness to strength training in patients with chronic respiratory diseases. It is clear from these studies, however, that peripheral muscle, particularly muscles of ambulation, are weak in patients with lung disease, exhibiting effort-dependent strength scores that are 70–80% of these measures in age-matched healthy subjects. The degree to which this dysfunction is accounted for by deconditioning, disease-related myopathy, or other causes is unclear. It is evident, however, that patients with chronic respiratory diseases can acquire and maintain substantial improvements in skeletal muscle function, physical function, and quality of life through participation in a well-structured program of resistance exercise training. Despite the positive, albeit limited, evidence that skeletal muscle dysfunction may be improved with resistance training, no clear guidelines are available for this purpose. This review discusses the skeletal muscle dysfunction that accompanies chronic respiratory disease and presents strategies for resistance exercise training that may be considered as part of pulmonary rehabilitation. These strategies are derived from the successful outcomes noted in studies using resistance training in patients with COPD as well as on extrapolations from extant guidelines used to develop strength, power, and endurance in healthy individuals.

Exercise intolerance almost invariably accompanies chronic respiratory disease. This reduced work capacity, however, cannot be explained by ventilatory limitations alone. Lung transplantation, for example, serves to reverse the ventilatory limitation in patients undergoing this procedure, but performance parameters such as aerobic capacity ($\dot{V}O_{2max}$) and the anaerobic threshold remain abnormally low (28,29). It has been suggested that the continued exercise intolerance observed after lung transplantation may be attributed to peripheral muscle dysfunction (12,20,29). Evidence is available suggesting that loss of muscle strength is proportional to the loss of muscle mass in patients with COPD and that there is preferential loss of muscle size and strength in the lower limbs (4).

The building evidence that peripheral muscle dysfunction contributes to the exercise intolerance seen in chronic respiratory diseases has recently received considerable attention (7,24) and has been shown to be significantly and independently related to increased use of health care resources (10). Resistance exercise training as a countermeasure to muscle dysfunction, on the other hand, has received relatively little attention, with scant information that might serve as guidelines for such training (3).

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PATIENTS WITH CHRONIC RESPIRATORY DISEASES HAVE WEAK MUSCLES

Only a small number of reports accumulated over the past 5 yr have documented the peripheral muscle weakness commonly seen in patients with chronic lung diseases. Almost all of these reports have dealt with a single disease entity, chronic obstructive pulmonary disease (COPD). Hamilton et al. (17), reporting on 785 patients with mild to moderate obstructive and nonobstructive pulmonary disease (FEV_1 65 $\pm$ 15% of predicted) and 919 healthy subjects of similar age, demonstrated that the patient group averaged strength scores that were 81% of the healthy group for the four muscle groups studied (Fig. 1).

In this same study, the authors noted that maximal cycle ergometer work rate in the pulmonary patients was 73% of that found in the healthy group. Maximal work capacity was significantly correlated with knee extensor strength in both healthy volunteers and patients with pulmonary disease (17). At any given knee extensor strength, peak work rate was significantly lower ($P < 0.001$) in the patients with pulmonary disease compared with healthy subjects (Fig. 2). Expressing knee extensor strength in quartiles, on the basis of the distribution of knee extensor strength in the healthy subjects, resulted in 44% of the patients with pulmonary disease scoring in the lowest quartile ("very weak"), 25% into the "weak" quartile, 19% into the "strong" quartile, and 12% into the "very strong" quartile. This large study convincingly emphasized the need to address the contribution of peripheral muscle weakness to the reduced exercise capacity observed in patients with chronic pulmonary disease.

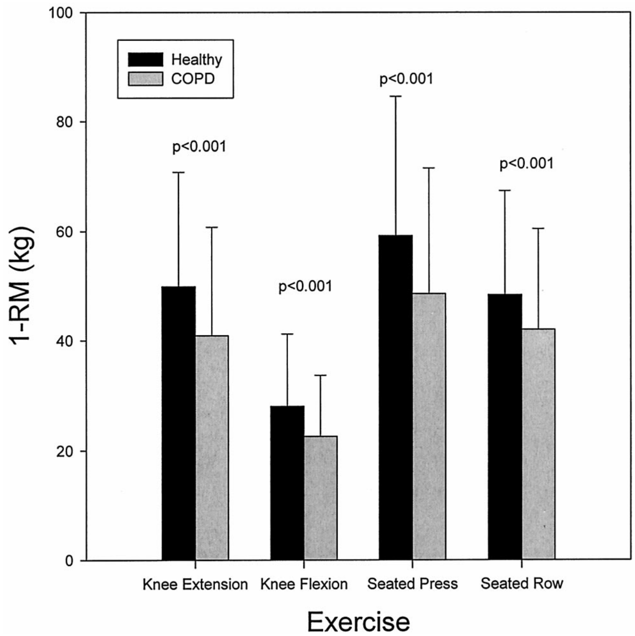

FIGURE 1—Maximum voluntary strength measured as one-repetition maximum (1-RM) in age-matched healthy subjects (*N* = 919) and in patients with COPD (*N* = 785). Columns represent mean values for 1-RM muscle strength normalized for differences in age, gender, and height. Error bars are standard deviations. Redrawn from data from Hamilton et al. (17).

Gosselink et al. (16) demonstrated that peripheral muscle strength was a significant correlate of $\dot{V}O_{2max}$ and 6-min walking distance in 41 patients with moderate to severe COPD (FEV_1 43 ± 19% of predicted). These researchers reported significant reductions in both peak isometric quadriceps torque and maximal isometric handgrip force measurements when compared against normal values corrected

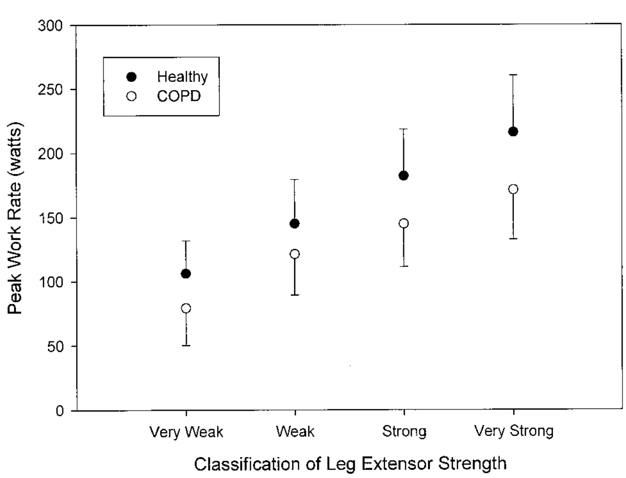

FIGURE 2—Relationship between peak work rate (W) and knee extensor strength (1-RM, kg) in healthy subjects (*closed circles*) and patients with COPD (*open circles*). Classification of knee extensor strength derived from quartiles determined from the distribution of strength scores among the healthy subjects. Knee extensor strength and peak work rates were normalized for differences in age, gender, and height. Redrawn from data derived from those reported by Hamilton et al. (17) shown as means ± SD. Error bars are shown in positive or negative direction only for healthy and COPD subjects, respectively, for clarity.

for age, gender, and body weight. Quadriceps force was 74% and handgrip force 82% of predicted. Expressed as a percentage of predicted, maximal handgrip force was significantly greater ($P < 0.02$) than percent of predicted quadriceps force, suggesting unequal loss of muscle strength in these two muscle groups. This difference may have resulted from greater use of handgrip muscles in performance of activities of daily living as compared with leg muscles. Using stepwise multiple regression, transfer factor for carbon monoxide along with quadriceps force and FEV_1 were significant determinants of $\dot{V}O_{2max}$, explaining 58% of the total variance in the model. For the 6-min walk, quadriceps force and maximal inspiratory pressure were the significant contributors to the multiple regression model, accounting for 45% of the common variance. From these data, Gosselink et al. concluded that both lung function and peripheral muscle strength were important contributors to the exercise limitations seen in patients with COPD (16).

Bernard et al. (4) reported that maximum voluntary strength measures assessed by the one-repetition maximum method (1-RM) for the quadriceps, pectoralis major, and latissimus dorsi muscles in 34 patients with moderate to severe COPD (43 ± 19% of predicted) were 73%, 84%, and 84%, respectively, of those seen in 16 healthy subjects. The lower strength values for the quadriceps were accompanied by thigh muscle cross-sectional areas that were 76% of those seen in the healthy, age-matched controls. The quadriceps strength to thigh muscle cross-sectional area ratios were similar between the healthy controls and the patients with COPD, suggesting preservation of thigh muscle contractile apparatus (4) and thus the potential for restoring muscle mass and strength through training. Bernard and colleagues (4) also evaluated the distribution of muscle weakness in lower versus upper body muscle groups by comparing 1-RM strength scores for the quadriceps, pectoralis, and latissimus dorsi muscle groups in patients with COPD with the mean strength scores achieved by the healthy controls. The relative strength of the quadriceps was significantly lower (60% of the mean value for healthy subjects) than that of the pectoralis or latissimus dorsi muscle groups (72% and 76% of the mean control values, respectively). These data tend to confirm the observations of Gosselink et al. (16) regarding the preferential loss of muscle strength in the lower extremity. Bernard et al. (4) demonstrated significant, positive relationships between FEV_1 (percent predicted) and quadriceps strength and thigh cross-sectional area as well as between peak $\dot{V}O_2$ and quadriceps strength and thigh muscle cross-sectional area. Their data suggest that deconditioning and the resultant disuse atrophy of especially lower limb skeletal muscle in patients with COPD are at least partial explanations for the observed peripheral muscle dysfunction and diminished exercise tolerance observed in these patients. Countermeasures such as resistance exercise training, especially for lower extremity muscle groups, may alleviate some of this dysfunction through restoration of muscle mass and strength.

The downward spiral of decreased activity and the consequent decreased muscular abilities are well known in patients with pulmonary disease (6). Although it appears clear that disuse atrophy is at least partially responsible for the muscle dysfunction, other mechanisms may contribute to these deficits. Possibilities include a specific myopathy (especially corticosteroid-induced myopathies among those individuals treated with corticosteroids over prolonged periods of time (9)), alterations in the contractile apparatus (22), poor nutritional status (11,21), chronic hypoxia (25), or combinations of these. Unfortunately, little is known about the responsiveness of patients with chronic respiratory diseases to countermeasures that may specifically ameliorate peripheral muscle dysfunction, especially therapeutic activities directed at combating muscle atrophy.

RESPONSES OF PATIENTS WITH COPD TO RESISTIVE TRAINING

Although exercise training is unable to improve lung function, specific types of exercise training (e.g., resistance training) have been shown to improve muscle function and performance of functional activities in patients with chronic pulmonary disease. Simpson et al. (27) randomized 34 patients with COPD (FEV_1 <40% of predicted, 58–80 yr of age) into a resistance training group and a nonexercising control group. Fourteen subjects in each group completed the study, with significantly more female subjects constituting the training group as compared with controls. Training consisted of an 8-wk program of resistance exercise training in which three sets of 10 repetitions for each of three exercises were performed 3 $d \cdot wk^{-1}$. The resistance progressed from an initial load of 50% of 1-RM in the first week to 85% of 1-RM in the final week of training. The 1-RM was reassessed every 2 wk, with training intensities consequently adjusted. Improvements in maximal voluntary strength ranged between 16% and 44% for the training group, with no significant change in the control group. In addition, endurance time (cycling at 80% pretraining peak work rates to fatigue) improved from 8.6 min to 15 min (74%), with no change observed in control subjects. No changes were observed for maximum cycle exercise capacity or 6-min walk distance in either group. Responses to a quality of life questionnaire developed for chronic lung disease revealed significant improvements in the resistance-trained group, but not the control group, for the domains of dyspnea, mastery, and fatigue (27).

Recognizing that lower extremity aerobic training improves exercise tolerance but has little effect on muscle atrophy or weakness in patients with COPD, Bernard and colleagues (5) compared the contribution of resistance exercise training to the more traditional "aerobic" exercise training (leg cycling). Neither control nor strength training only groups were included in this study. Subjects completing the study (N = 15 in the aerobic group and N = 21 in the aerobic plus strength training group) had mean ± SD FEV_1 values of 45 ± 15% of predicted. Aerobic training was similar for both groups, consisting of 30 min of leg cycling, three times per week using 80% of the peak work rate achieved during the baseline incremental exercise test. In addition to this aerobic training, the aerobic plus strength training group performed two sets of 8–10 repetitions per set for each of four exercises using 60% of the initial 1-RM. Sets and loads were progressed to three and 80% 1-RM, respectively, over the 12 wk of the study. When subjects could complete more than 10 repetitions per set, load was increased. Patients randomly assigned to the aerobic exercise plus resistance training group demonstrated significant improvements in thigh muscle cross-sectional area (8%), and strength in the quadriceps (20%) and pectoralis major (15%) muscle groups. These strength improvements were significantly greater than those noted in the aerobic training only group. Quadriceps strength increased significantly in the aerobic training only group (8%), whereas thigh muscle cross-sectional area did not significantly change. One might argue that the aerobic plus resistance training group performed more total work over the course of the 12 wk of training and the superior improvements were to be expected. This, of course, would not apply to changes in pectoralis major muscle strength. Nevertheless, Bernard and colleagues were successful in demonstrating that peripheral muscle in COPD patients can undergo structural and functional adaptation to strength training when the training stimulus is appropriate. In this study, strength training, in addition to the familiar aerobic training of pulmonary rehabilitation, did not result in additional improvements in peak cycle exercise work rate, $\dot{V}O_{2max}$, 6-min walk distance, or health-related quality of life when compared with the aerobic training only group. Bernard et al. (5) suggested that the magnitude of the changes in peripheral muscle function observed in their study might not have been adequate to improve these measures of aerobic function and quality of life and that further studies will be required to determine if greater improvements in muscle function translate into further improvements in physical function. They also noted that the use of strength training in their study induced less dyspnea than cycling exercise and consequently was well tolerated by the subjects. Use of resistance training also helped diversify training sessions and thus maintain patient interest and motivation.

Recently, Clark et al. (8) compared measures of isokinetic muscle function between patients with mild COPD (FEV_1 77 ± 23% of predicted) and age-matched healthy but sedentary controls. When age, height, weight, gender, and the coefficient for "COPD" were entered into multiple regression analysis, "COPD" accounted for a significant reduction in three out of four measures of isokinetic muscle function. In a second phase of this study, the 43 COPD patients were randomly allocated into a group who received 12 wk of resistance exercise training (N = 26) or to a control group (N = 17). Characteristics of the resistance training program are presented in Table 1. The training group significantly improved "isotonic" strength, isokinetic endurance, but not isokinetic peak torque when compared with nontraining controls. Treadmill endurance, but not cycle ergometer $\dot{V}O_{2max}$, improved significantly in the training group. The improvement in treadmill endurance reported by Clark et al. (8) supports the 74% improved cycle endurance time reported by Simpson et al. (27). If walking and cycling

TABLE 1. Summary of training elements used in resistance training programs for patients with COPD.

Study	Resistance Exercises Reported (Training Equipment)	Study period (wk)	Frequency (d·wk–1)	Sets	Repetitions per Set	Load	Rest Interval (min)
Simpson et al. (27)	Single arm curl Single leg extension, Single leg press (Global Gym)	8	3	3	10	50–85% 1-RM	Not specified
Bernard et al. (5) (aerobic plus strength group)	Seated press Latissimus pulls Leg press Knee extension (Hydrafitness)	12	3	2–3	8–10	60–80% 1-RM	Not specified
Storer et al. (unpublished)	Leg press Seated chest press (Keiser)	154	2+	1–3	6–12	60%1-RM to 6–8 RM	1 min between sets, 2 min between exercises
Casaburi et al. (unpublished)	Leg press Calf press (Keiser)	16	3	3	8–12	60–80% 1-RM	1 min between sets, 2 min between exercises
Clark et al. (8)	5 lower extremity 3 upper extremity (Multigym)	12	2	3	10	70% 1-RM	No specified
Troosters et al. (30)	3 upper extremity 1 lower extremity (Multigym)	26	3/wk first 13 wk 2/wk last 13 wk	3	10	60% 1-RM	Not specified

endurance can be taken as measures of functional performance, these two studies suggest that resistance exercise training has the potential to improve functional performance in some subjects with COPD.

Reporting on 100 consecutive patients with COPD (FEV_1 <43% of predicted) referred to an outpatient rehabilitation program, Troosters et al. (30) identified significant and relevant improvements in maximal exercise performance, 6-min walk distance, peripheral muscle strength (quadriceps peak isometric torque), respiratory muscle strength, and quality of life among patients who completed a 6-month comprehensive training program compared with nonexercising controls (30). In addition to the resistance training program summarized in Table 1, exercise training consisted of cycling at 60–80% of maximal cycle work load achieved during initial assessments, walking at 60–80% of the walking speed determined during initial 6-min walk assessments, and one to three 2-min bouts of arm cranking and stair climbing. Training session durations were 1.5 h. The improvements noted at 6 months persisted, except for inspiratory muscle strength, when reassessed during follow-up at 18 months. Although the results of this study are impressive, it is difficult to ascertain the independent effects of resistance training on the outcome measures reported in this study.

Storer et al. (unpublished data) have conducted a long-term observational study of 12 patients (9 women, 3 men) who had moderate COPD (FEV_1 49 ± 24% of predicted) and averaged 67 yr of age. One subject had received a bilateral lung transplant after 1 yr. All 12 subjects had participated for the 3 yr of this observational study in a 2-d·wk^{-1} comprehensive exercise training program consisting of warmup and range-of-motion exercises, aerobic exercise training on treadmills and cycle ergometers, and progressive resistance exercise training for major muscle groups (Table 1). Maximum voluntary strength was assessed by 1-RM annually using the same equipment that was used for training (Keiser Sport, Fresno, CA). Figure 3 depicts the changes from baseline in leg press and chest press strength observed over the 3-yr period. Leg press strength increased 77% during the first year; this improvement was essentially maintained for the next 2 yr. The change in chest press strength developed more slowly, with a 49% increase after the first year, but continued to increase in year 2, exhibiting a 97% increase from baseline and a 116% increase from baseline after 3 yr. The large standard deviations are noteworthy and reflect individual differences in ability to train, the training response, compliance, and exacerbations of acute illness. Overall, these data suggest that not only can patients with COPD achieve significant improvements in strength, but they can also maintain or further improve those strength levels over a 3-yr period.

RESISTANCE EXERCISE TRAINING PROGRAMS IN COPD

As with endurance training, there is no consensus regarding the characteristics of an optimal resistance training

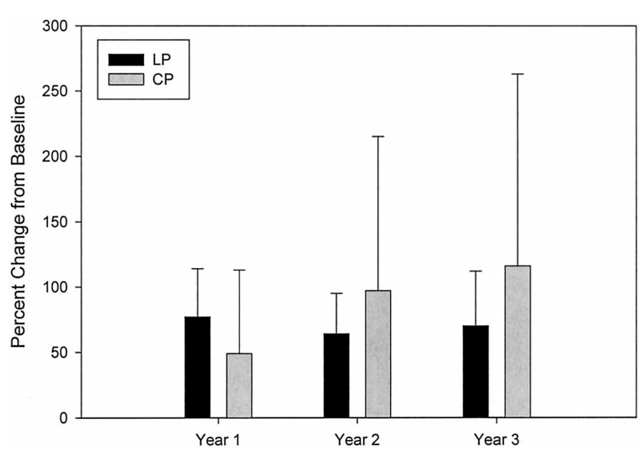

FIGURE 3—Percent changes from baseline in one-repetition maximum leg press and chest press strength in 12 COPD patients performing resistance exercise training 2 d·wk^{-1} over 3 yr as part of a comprehensive pulmonary rehabilitation program (Storer et al., unpublished data). Data are means ± SD.

program for patients with pulmonary disease. Extrapolations from programs used to develop strength, power, and endurance in healthy individuals (2,14) and the successful outcomes noted above in those studies using resistance training in patients with COPD (5,8,27,30) offer reasonable templates for program design. Table 1 identifies elements that are common to the design of resistance training programs (14) and compares the application of these elements in the few published resistance exercise training studies in patients with COPD reported to date plus approaches used in our laboratories in studies currently underway. The program designated as Storer et al. (unpublished data) is from an ongoing pulmonary rehabilitation program. The program designated as Casaburi et al. (unpublished data) illustrates the structure of the resistance training component in our study of anabolic interventions in men with COPD.

A synthesis of the data presented in Table 1 would suggest training frequencies of 2–3 $d \cdot wk^{-1}$, with one to three sets of 8–10 repetitions using loads progressing from 50–85% of a current 1-RM assessment. Studies using some combination of these guidelines have demonstrated efficacy and safety, revealing substantial improvements in muscle strength (5,8,27), and size (5) with no untoward effects in patients with mild to moderate COPD.

It should be noted that some recent resistance training guidelines for healthy individuals have suggested use of a single set of 8–12 repetitions to fatigue (2). However, current exercise and physical activity guidelines for older adults (the majority of patients with COPD fall into this group) recommend two to three sets (1). This latter recommendation also indicates that one set may be adequate, but identifies the need for further studies on the components of resistance training program design in order to optimize resistance training regimens in older adults. Although the ideal number of sets is unsettled, we have found that a single set of an exercise for each body part may be an ideal starting point for people with COPD, but principles of progression suggest that, to maximize the response, two or possibly three sets would be more advantageous as the patient progresses. This point has recently been addressed by Sanborn et al. (26).

In our experience, fewer rather than more repetitions per set seem to be better tolerated by the COPD patient, with 6–10 repetitions appearing optimal. As with endurance training, a gradual introduction to resistance training, perhaps with one set of 8–10 repetitions using 50–60% of 1-RM for major muscle groups, will avoid excessively sore muscles and allow the participant to establish a training base from which the rehabilitation specialist may progress. We typically observe our beginning patients able to progress to a second set within 3–4 wk of twice-weekly training. After another 3–4 wk of adaptation, most patients can tolerate increased percentages of newly established 1-RM values. Loads for the lower extremity exercises can generally increase by 5–10%, whereas a 5–7% increase in percent 1-RM for upper extremity exercises is more appropriate.

Most of the resistance training programs used in research conducted on patients with COPD have used a percentage of the 1-RM to establish the training load (Table 1). Loads as high as 80% of the pretraining 1-RM have been successfully applied in healthy, frail elderly (13,15) and in patients with chronic pulmonary disease (5,27) with no ill effects. Alternatively, load assignment that uses a given number, or range of repetitions maximum (e.g., 8–12 RM), may be used to establish the training resistance for each exercise. This is sometimes referred to as RM target or target zone (14). In this example, a weight is identified through trial and error that can be lifted at least 8 times, but not more than 12 times before failure. There are several advantages to using the RM target approach to load selection as opposed to the percent 1-RM method. First, the training stimulus at a fixed percentage of 1-RM varies with the muscle mass used and the training state of the subject (18,19). Thus, 80% of 1-RM for the leg press exercise may result in a different number of repetitions completed per set than for triceps extensions at the same 80% 1-RM load. Second, assigning loads on the basis of a percentage of 1-RM requires frequent reassessment of the 1-RM so that load may be increased proportionally with strength increases over time. Otherwise, continuing with loads calculated from a percentage of the initial 1-RM will result in a reduced training intensity, as the load becomes a progressively smaller proportion of an increasing 1-RM. Reassessing the 1-RM for several exercises on a frequent basis is time consuming and takes away from training time. Use of a target RM value or range (e.g., 6–10 RM) is self-adjusting with respect to load, allowing the patient to further improve while continuing to perform the prescribed number of repetitions. In our ongoing pulmonary rehabilitation program, we find that gradually increasing loads from 60–70% 1-RM to 10–12 RM, then to 6–8 RM is well tolerated by most participants with no untoward effects. An important caveat to this approach centers on the potential for an abnormal pressor response. Blood pressure responses are higher when repetitions to failure are performed in the range of 50–90% 1-RM. It is prudent, therefore to evaluate blood pressure both at rest and during weight lifting exercise.

Other considerations in the formulation of a resistance training program for people with COPD include type of resistance used, the rest interval between sets or exercises, choice of exercises, and safety considerations. Many types of resistance are available, including elastic resistance, machine weights, free weights, and body weight. Choice of equipment is often dictated by what is available. However, almost any form of resistance will suffice so long as it can be graded in its application, is safe to use, and has some motivational appeal to the participant. The latter is often accomplished when the participant sees a known amount of weight move. Consideration should be given to the minimal weight that can be set for any given exercise. Some types of weight machines have minimal resistances that are too high or weights that are in increments that are too large for some debilitated COPD patients. Elastic resistance providing low force requirements may be ideal for some very debilitated patients. The ideal rest interval between sets is difficult to establish for the patient with COPD primarily because of varying degrees of dyspnea and/or oxyhemoglobin desaturation. Although a 1-min rest interval between sets might be attempted, in practice, 2–3 min may be required. Number and choice of exercises may be dictated by patient goals and needs assessment (e.g., improving ability to climb stairs in the patient's domicile) or by contraindications such as arthritic joints or osteoporosis (a particular problem in patients undergoing long-term corticosteroid therapy). A free weight squat, for example, would typically not be appropriate in the COPD population. However, performing the seated leg press exercise or repetitions of standing up from a bench or chair while holding progressively heavier dumbbells on the hips may be acceptable alternatives. If patients cannot stand up from the chair or bench with their body weight alone, the seat height may be elevated.

Resistance training, even at high intensities, has been shown to be safe and beneficial for healthy older adults (2,13,15). No untoward responses have been reported in resistance training studies with COPD patients even with training intensities as high as 85% 1-RM (Table 1). Additional safety concerns include the need to use biomechanically safe lifting technique that must be taught and reinforced often. A part of correct lifting technique includes proper breathing, avoiding the Valsalva maneuver. In order to help maintain oxyhemoglobin saturation levels in the appropriate range (≥90%), diaphragmatic and pursed lip breathing should be taught and practiced and performed as needed. It may be necessary to periodically monitor oxygen saturation with a pulse oximeter and the level of dyspnea with a visual analog scale (23). Periodic blood pressure measurements are needed in order to monitor the pressor response to the resistance exercise.

The training strategies described above have been shown to be safe and effective in improving muscle strength, size, and function in small groups of patients with COPD. However, the effectiveness of resistance training alone, or in combination with aerobic exercise training in a comprehensive rehabilitation program, has not been fully evaluated and thus may not be appropriate for every patient with chronic respiratory disease. Nevertheless, on the basis of the cumulative experience at the present time, certain recommendations can be made to assist the pulmonary rehabilitation practitioner with resistance exercise prescription (Appendix B). These recommendations are subject to individual adjustment on the basis of physical, physiological, and psychological factors including patient tolerance and safety. It is anticipated that further research and clinical experience will lead to refinement of the resistance exercise prescription and enable extension of these recommendations to include patients with all types of chronic pulmonary disease. Refinement of the resistance exercise prescription will help in the development of optimal training programs for these patients in order to overcome the muscular weakness and loss of functional ability that attends their disease.

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