Peripheral Muscle Strength Training in Bed-Bound Patients With COPD Receiving Mechanical Ventilation: Effect of Electrical Stimulation

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Effect of Electrical Stimulation

Ercole Zanotti, MD; Guido Felicetti, MD; Maurizio Maini, MD; and Claudio Fracchia, MD

Study objective: **To compare the effects of active limb mobilization (ALM) with or without electrical stimulation (ES) on muscle strength, respiratory rate (RR), heart rate, oxygen saturation, and time needed to transfer from bed to chair in two groups of patients with COPD.**
Design: **Randomized, controlled study.**
Setting: **Respiratory high-dependency care unit.**
Patients: **Twenty-four bed-bound patients with chronic hypercapnic respiratory failure due to COPD who were receiving mechanical ventilation, with marked peripheral muscle hypotonia and atrophy.**
Methods: **Patients were randomly assigned either to ALM alone or to ALM plus ES (ALM/ES). ES was applied using square-wave alternate, symmetric, and compensated impulses for 30 min bid. The duration of treatment was 28 days for all patients.**
Results: **Muscle strength improved significantly in the overall group of patients (from 1.75 ± 0.73 to 3.44 ± 0.65, $p < 0.05$). Comparing the change (end minus beginning) of the analyzed variables, ALM/ES significantly improved muscle strength (2.16 ± 1.02 vs 1.25 ± 0.75, $p = 0.02$) and RR (− 1.91 ± 1.72 vs 0.41 ± 1.88, $p = 0.004$), and decreased the number of days needed to transfer from bed to chair (10.75 ± 2.41 days vs 14.33 ± 2.53 days, $p = 0.001$).**
Conclusion: **In bed-bound patients with COPD receiving mechanical ventilation, with marked peripheral muscle hypotonia and atrophy, application of ES in addition to classical ALM significantly improved muscle strength and decreased the number of days needed to transfer from bed to chair.** ***(CHEST 2003; 124:292–296)***

Key words: COPD; electrical stimulation; exercise intolerance; rehabilitation; peripheral muscle dysfunction

Abbreviations: ALM = active limb mobilization; ALM/ES = active limb mobilization plus electrical stimulation; ES = electrical stimulation; HR = heart rate; RR = respiratory rate; Sat = oxygen saturation

Patients affected by COPD very frequently complain of exercise intolerance.[1] This exercise intolerance is usually attributed to abnormal lung mechanics, impaired gas exchange, and destruction of the pulmonary vascular bed, which all directly influence the capacity to sustain exercise.[2] However, patients with COPD often also have skeletal muscle dysfunction.[1–3] In 1992, Killian and colleagues[4] suggested the importance of peripheral skeletal muscle dysfunction on exercise capacity in patients with COPD. A few years later, Hamilton and colleagues[5] showed that approximately 70% of patients with chronic lung disease had less quadriceps strength than normal subjects of a similar age. Since skeletal muscle dysfunction can, fortunately, be a remediable source of exercise intolerance,[2] it is reasonable to speculate that rehabilitation could increase peripheral muscle function, thus increasing exercise tolerance. This has already been demonstrated to be the case both in normal subjects[6] and in patients with COPD[7,8]; however, the training strategies most commonly used in patients with COPD focused on lower-limb endurance training.[2] To the best of our knowledge, only two studies[9,10] gave an account of

*From the Pulmonary Department (Drs. Zanotti and Fracchia) and Physical Medicine and Rehabilitation Department (Drs. Felicetti and Maini), Scientific Institute of Montescano, Fondazione Salvatore Maugeri IRCCS, Montescano, Italy.
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Correspondence to: Ercole Zanotti, MD, Fondazione S. Maugeri, Divisione di Pneumologia, Istituto Scientifico di Montescano, 27040 Montescano (PV), Italy; e-mail: ezanotti@fsm.it

the effects of strength training in patients with COPD; however, strength training is suggested as a rational component of exercise training during pulmonary rehabilitation.[11]

The use of electrical stimulation (ES) has been proven to improve muscle strength.[12,13] Moreover, it has been shown[12] that to reach an equivalent rate of muscle strengthening, a higher intensity of muscle contraction must be used during voluntary exercise than during ES. This may lead to an increase in heart rate (HR), particularly in elderly subjects. Using ES, a similar degree of muscular contraction can be reached without increasing cardiovascular work.[14]

The primary aim of this study was to compare the effects of two different treatments on peripheral muscle strength. We also considered whether ES could effectively strengthen peripheral muscles without influencing cardiovascular function; for this reason, we studied respiratory rate (RR), HR, and oxygen saturation (Sat). Finally, we postulated that if the application of ES does improve peripheral muscle strength, this should influence the patients' functional ability; therefore, we looked for differences in the number of days needed to transfer from bed to chair. The patients were randomly assigned to receive the standard physical rehabilitation protocol of active limb mobilization (ALM) or ALM plus ES (ALM/ES).

Materials and Methods

Patients

The study group was a convenience sample formed of the first 24 subjects who met the inclusion criteria, consented to participate, and completed 28 days of the rehabilitation program. Our entry criteria were chronic hypercapnic respiratory failure due to COPD (the diagnosis of COPD was made according to the Global Initiative for Chronic Obstructive Lung Disease Workshop Report[15]), need for invasive mechanical ventilation via a tracheostomy, and the presence of a severe peripheral muscle atrophy. All the patients were referred to our respiratory high-dependency care unit from surrounding ICUs and had been confined to bed for at least 30 days. Subjects were considered eligible for the study if they were in a clinically stable state (*ie*, had no evidence of acute exacerbation and had no change in medications in the previous 4 weeks). Patients who had received inhaled steroids were enrolled in the study. Patients who had been treated with systemic corticosteroids and neuromuscular blocking agents for > 5 days while they were in the ICU were excluded. This is because it has been demonstrated that acute myopathy may occur in critically ill patients receiving corticosteroids with or without neuromuscular blocking agents,[16] and that a high dose of steroids for only 5 days, in the absence of other therapy, may induce serious respiratory and limb muscle weakness.[17] Exclusion criteria were a history of diseases other than COPD, in particular neurologic disease, and the need for treatment with systemic steroids during the rehabilitation period. The study was approved by the institutional ethics committees.

Measures

Primary Measures: Peripheral muscle strength was the primary outcome of this study and was evaluated at the beginning of the training and every 2 days during the rehabilitation program using a score commonly adopted in physical medicine.[18] This scoring system is shown in Table 1. Muscle strength was evaluated independently by the referring physician and the chief therapist. Exercise training was performed by a member of the rehabilitation team who was unaware of the aim of the study. ALM of the upper and lower limbs was performed as soon as possible in all patients.

Twelve patients were randomly assigned to receive ALM/ES. The stimulator used was a commercially available two-channel model (SportTrainer; Actionfit; Forlì, Italy), which generated bipolar, biphasic, asymmetric rectangular pulses. Both ALM and ALM/ES were performed bid, 5 d/wk for 4 weeks, beginning with the maximum time tolerated by the patient and gradually increasing the time of training up to 30 min. Each ES session comprised 5 min at 8-Hz pulse width 250 microseconds and then 25 min at 35-Hz pulse width 350 microseconds. All treatment sessions took place on the patient's bed. Surface electrodes were bilaterally positioned on the quadriceps femoris and on vastus glutei.

Secondary Measures: Cardiorespiratory function and the number of days needed to transfer from bed to chair were recorded. Cardiorespiratory function included Sat, HR, and RR, which were acquired continuously using a monitoring system (S7010; Marquette Electronics; Milwaukee, WI).

Statistical Analysis

Results are expressed as mean ± SD. Differences between the two groups were evaluated by paired Student *t* test. A p value < 0.05 was considered statistically significant.

Results

The patients' demographic and anthropometric characteristics and blood gas values are shown in Table 2. All patients tolerated both ALM and ALM/ES; nobody refused the procedures. There were no deaths during the study period. Eleven patients were successfully weaned from mechanical ventilation and tracheostomy, 7 patients were weaned from mechanical ventilation but were discharged with a tracheostomy, and 6 patients were discharged still receiving mechanical ventilation.

There were no statistically significant differences in baseline strength, HR, RR, and Sat between the

Table 1—*Score of Muscle Strength*

Score	Definition
5	Normal power
4	Muscle moves joint against resistance, as well as gravity, but less effectively than normal
3	Muscle moves joint against gravity, but not against resistance
2	Muscle moves joint with gravity eliminated
1	Flicker of muscle contraction but no movement of joint
0	No muscle contraction visible or felt

Table 2—*Baseline Demographic and Anthropometric Characteristics and Blood Gas Values

Characteristics	ALM Group	ALM/ES Group
Patients, No.	12	12
Age, yr	64.5 ± 4	66.2 ± 8
Male/female gender, No.	8/4	9/3
Weight, kg†	58.4 ± 4.2	61.2 ± 7.4
Body mass index†	22.4 ± 3.7	24.5 ± 2.4
pH	7.41 ± 0.10	7.42 ± 0.12
$Paco_2$, mm Hg	46.2 ± 4.1	44.5 ± 3.7
Pao_2/Fio_2	258.6 ± 39.7	263.1 ± 45.2
Time in ICU, d	47.4 ± 19.2	51.8 ± 14.7

*Data are presented as mean ± SD unless otherwise indicated. Fio_2 = fraction of inspired oxygen.
†Weight and consequently body mass index may not be accurate since the patients were bed bound.

ALM and ALM/ES groups (Table 3). Both ALM and ALM/ES led to a significant improvement in muscle strength. In particular, at the beginning, muscle strength was estimated to be 1.83 ± 0.71 in the ALM group and 1.66 ± 0.77 in the ALM/ES group, while at the end of the treatment it was 3.08 ± 0.51 ($p = 0.0006$) and 3.83 ± 0.57 ($p = 0.0001$), respectively. RR and HR did not change significantly between the beginning and the end of the treatment, while Sat significantly improved ($p = 0.04$) in the ALM/ES group. These results are summarized in Table 4.

The comparison of the change (*ie*, end minus beginning) in muscle strength and other variables between the two groups is shown in Table 5. Compared to ALM alone, ALM/ES was able to further increase muscle strength (2.16 ± 1.02 vs 1.25 ± 0.75, $p = 0.02$); moreover, ALM/ES was able to decrease RR (− 1.91 ± 1.72 vs 0.41 ± 1.88, $p = 0.004$), while HR and Sat were not influenced. There was a significant difference in the number of days needed to transfer from bed to chair between patients treated with ALM/ES and those treated with only ALM (10.75 ± 2.41 days vs 14.33 ± 2.53 days, respectively; $p = 0.001$).

Table 3—*Comparison of Muscle Strength, HR, RR, and Sat Between the Two Populations at the Beginning of the Study

Variables	ALM Group	ALM/ES Group	p Value
Strength	1.83 ± 0.71	1.66 ± 0.77	NS
HR	91.58 ± 5.24	95.9 ± 7.51	NS
RR	22.5 ± 2.31	21.75 ± 2.89	NS
Sat	93.66 ± 2.87	92.16 ± 3.73	NS

*Data are presented as mean ± SD; NS = not significant.

Discussion

Exercise training is able to improve muscle strength even in bed-bound patients with COPD and a severe degree of functional impairment who are receiving mechanical ventilation. The addition of ES may further enhance the effects of classical rehabilitation treatment.

People with COPD are often confined to their house, isolated, and depressed as they try to avoid dyspnea. These features lead to significant debilitation, which further worsens dyspnea. Casaburi[1] pointed out that the list of effective therapies available for these patients is short, underlining that rehabilitative exercise training aimed at curing dysfunction of the peripheral muscles may be a proper addition to this short list. Among the possible mechanisms of muscle dysfunction, deconditioning is almost certainly a major contributor to the muscle dysfunction seen in patients with COPD.[1] Deconditioning causes substantial decreases in strength and endurance and can lead to atrophy of the muscles of ambulation. Dysfunction of the skeletal muscles, particularly the muscles of ambulation, contributes to the exercise intolerance that is a very frequent characteristic of patients with COPD.[19] Consequently, pulmonary rehabilitation and specifically rehabilitative exercise training ought to focus on exercise tolerance.

It has already been shown that pulmonary rehabilitation is able to improve exercise tolerance in patients with COPD.[19,20] COPD is characterized by abnormal lung mechanics, impaired gas exchange, and destruction of the pulmonary vascular bed[2]; since pulmonary rehabilitation obviously cannot affect these features, its effects have been attributed to psychological factors, including improved motivation and decreased sensitivity to dyspnea.[21] However, the role of pulmonary rehabilitation on skeletal muscles should not be underestimated; indeed, skeletal muscle dysfunction is a remediable source of exercise intolerance.[2]

We decided to study bed-bound patients because we believe that they are the best model of extreme dysfunction of skeletal muscles. The fact that our patients were still receiving mechanical ventilation was a "guarantee" both of their severe functional impairment and that they had undergone a considerable period of immobility. The patients had been referred to our respiratory high-dependency care unit from surrounding ICUs for an attempt to wean them from mechanical ventilation and for pulmonary rehabilitation. Application of ES was decided after preliminary experience with a very small number of patients.[22] ALM of both upper and lower limbs was em-

Table 4—*Muscle Strength Score, RR, HR, and Sat at the Beginning and at the End of Treatment

Variables	ALM/ES			ALM		
	Beginning	End	p Value	Beginning	End	p Value
Strength	1.66 ± 0.77	3.83 ± 0.57	0.0001	1.83 ± 0.71	3.08 ± 0.51	0.0006
HR	95.9 ± 7.51	92 ± 6.96	NS	91.58 ± 5.24	88.83 ± 4.52	NS
RR	21.75 ± 2.89	19.83 ± 2.62	NS	22.5 ± 2.31	22.91 ± 2.67	NS
Sat	92.16 ± 3.73	94.58 ± 1.44	0.04	93.66 ± 2.87	94.33 ± 1.37	NS

*Data are presented as mean ± SD; see Table 3 for definition of abbreviation.

ployed, but ES was applied only to the lower limbs considering that upper-limb strength is relatively preserved in COPD, probably because the upper-limb muscles are more normally involved in activities of daily living.[2] Moreover, ES works on muscle strength, which is dramatically impaired in bed-bound patients. Surprisingly, muscle strength has been scarcely studied: COPD literature has almost exclusively focused on endurance activities.[3] Indeed, reduced endurance (*ie*, fatigue) seems to be the dominant limiting factor in peripheral muscles in these patients; however, the importance of muscle strength is now emerging.[23] It has been demonstrated[23] that the reduction in quadriceps strength averages 20 to 30% and that quadriceps strength correlates significantly with 6-min walking distance and maximal oxygen uptake in patients with COPD.[24] Moreover, muscle strength is significantly correlated with symptom intensity during incremental exercise testing.[4] Changes in muscle strength have been demonstrated to correlate significantly with changes in exercise capacity.[25] Peripheral muscle strength training has been shown to improve maximal muscle strength, exercise endurance capacity, and quality of life.[9] A editorial[26] on peripheral muscle wasting in COPD pointed out that probably the best available therapeutic modality to preserve muscle mass is strength training.

In our patients, the first evaluations of muscle strength were made independently by both the referring physician and the chief therapist. The muscle strength score at hospital admission was low (1.75 ± 0.73). According to the usual systems used for the evaluation of muscle strength,[18] this low score indicates that the evaluator can see a muscle contraction, but the patient is not able to move the joint unless gravity is eliminated. Using a score that considers the percentage of deficit and considering 0% the normal power,[27] our patients showed a muscle impairment ranging from 50 to 99%. This certifies their extreme degree of skeletal muscle dysfunction. It is important to emphasize that scores from 0 to 3 are objective scores.[27] Patients began exercise training as soon as possible (*ie*, when a stable clinical condition was reached) and both the duration and the intensity of the training were gradually increased. The training yielded a significant increase in muscle strength (3.44 ± 0.65) in the whole population. This means that at the end of the training period, patients were able to move muscles against gravity. The degree of impairment at the end of the training ranged from 25 to 50%.

Table 5—*Comparison of the Change (End − Beginning) in Muscle Strength and Other Variables Between the Two Groups

Variables	ALM/ES	ALM	p Value
Strength	2.16 ± 1.02	1.25 ± 0.75	0.02
HR	−3.83 ± 2.55	−2.75 ± 4.90	NS
RR	−1.91 ± 1.72	0.41 ± 1.88	0.004
Sat	2.41 ± 2.92	3.13 ± 3.31	NS

*Data are presented as mean ± SD; see Table 3 for definition of abbreviation.

The addition of ES to the standardized therapy led to further significant improvements. Indeed, the muscle strength score was similar in the two groups at admission (Table 3), but the final result was significantly different depending on which technique had been used; a higher score was reached when ES was added to ALM than when ALM was used alone. ES was administered during the period of exercise; once the electrostimulator had been applied, the therapist began the training exercises, handling the leg just during the electrical stimulation, so taking advantage of the impulses. In other words, the muscle contractions were stimulated by both the patient's voluntary movement and the electrical impulse.

Besides producing an additional increase in muscle strength, the combination of ALM and ES also shortened the time before the patient was able to transfer from bed to chair. This could lead to a decrease in complications associated with being bedridden, such as bedsores, pneumonia, and pulmonary embolism.

Limitation of the Study

We acknowledge that our study is somewhat limited by its small sample size; however, the sample was selected very carefully, adopting strict entry criteria, in order to exclude possible confounding variables. In particular, we tried to avoid any possible influence from drugs or other diseases that could have an effect on peripheral muscle strength. Our results confirm, in a larger population, what we found in a first investigation[22] and, therefore, we can speculate that is unlikely that significant discrepancies would emerge even with substantially larger numbers.

In conclusion, in bed-bound patients with severe COPD and still receiving invasive mechanical ventilation, ALM/ES improved peripheral muscle strength. This combined technique was well tolerated and, in comparison to ALM only, led to a reduction in RR. Patients were able to sit earlier than usual; this means an increase of functional ability and improvement of quality of life. The application of ES is safe, cheap, and reliable. It can be performed in any hospital setting, from the ICU to the general ward, and likely could shorten the duration of hospital stay in less severely ill patients.

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References

1 Casaburi R. Skeletal muscle function in COPD. Chest 2000; 117:267S–271S
2 Skeletal muscle dysfunction in chronic obstructive pulmonary disease: a statement of the American Thoracic Society and European Respiratory Society. Am J Respir Crit Care Med 1999; 159:S1–S40
3 Gosker HR, Wouters EFM, van der Vusse GJ, et al. Skeletal muscle dysfunction in chronic obstructive pulmonary disease and chronic heart failure: underlying mechanisms and therapy perspectives. Am J Clin Nutr 2000; 71:1033–1047
4 Killian KJ, Leblanc P, Martin DH, et al. Exercise capacity and ventilatory, circulatory, and symptom limitation in patients with chronic airflow limitation. Am Rev Respir Dis 1992; 146:935–940
5 Hamilton AL, Killian KJ, Summers E, et al. Muscle strength, symptom intensity and exercise capacity in patients with cardiorespiratory disorders. Am J Respir Crit Care Med 1995; 152:2021–2031
6 Holloszy JO, Coyle EF. Adaptations of skeletal muscle to endurance exercise and their metabolic consequences. J Appl Physiol 1984; 56:831–838
7 Serres I, Varray A, Vallet G, et al. Improved skeletal muscle performance after individualized exercise training in patients with chronic obstructive pulmonary disease. J Cardiopulm Rehabil 1997; 17:232–238
8 O'Donnell DE, McGuire M, Samis L, et al. General exercise training improves ventilatory and peripheral muscle strength and endurance in chronic airflow limitation. Am J Respir Crit Care Med 1998; 157:1489–1497
9 Simpson K, Killian KJ, McCartney N, et al. Randomised controlled trial of weightlifting exercise in patients with chronic airflow limitation. Thorax 1992; 47:70–75
10 Clark CJ, Cochrane JE, Mackay E. Low intensity peripheral muscle conditioning improves exercise tolerance and breathlessness in COPD. Eur Respir J 1996; 9:2590–2596
11 Pulmonary rehabilitation 1999: official statement of The American Thoracic Society. Am J Respir Crit Care Med 1999; 159:1666–1682
12 Cabric M, Appel HJ. Effect of electrical stimulation of high and low frequency on maximum isometric force and some morphological characteristics in man. J Sports Med 1987; 8:256–260
13 Currier DP, Mann R. Muscular strength development by electrical stimulation in normal individuals. Phys Ther 1983; 63:915–921
14 Caggiano E, Emrey T, Shirley S, et al. Effects of electrical stimulation or voluntary contraction for strengthening quadriceps femoris muscles in an aged male population. J Orthop Sports Phys Ther 1994; 20:22–28
15 Global Strategy for the Diagnosis, Management, and Prevention of Chronic Obstructive Pulmonary Disease: NHLBI/WHO Global Initiative for Chronic Obstructive Lung Disease (GOLD) Workshop Summary. Am J Respir Crit Care Med 2001; 163:1256–1276
16 Jantz MA, Sahn SA. Corticosteroids in acute respiratory failure. Am J Respir Crit Care Med 1999; 160:1079–1100
17 Nava S, Fracchia C, Callegari G, et al. Weakness of respiratory and skeletal muscles after a short course of steroids in patients with acute lung rejection. Eur Respir J 2002; 20:497–499
18 Guides to the evaluation of permanent impairment. 4th ed. Chicago, IL: American Medical Association, 1994
19 Casaburi R. Exercise training in chronic obstructive lung disease. In: Casaburi R, Petty TL, eds. Principles and practice of pulmonary rehabilitation. Philadelphia, PA: Saunders, 1993; 204–224
20 Ries AL, Carlin BW, Carrieri-Kohlman V, et al. Pulmonary rehabilitation: evidence based guidelines. Chest 1997; 112: 1363–1396
21 Haas F, Salazar-Schicchi J, Axen K. Desensitization to dyspnea in chronic obstructive pulmonary disease, In: Casaburi R, Petty TL, eds. Principles and practice of pulmonary rehabilitation. Philadelphia, PA: Saunders, 1993; 241–251
22 Zanotti E, Felicetti G, Maini M, et al. Peripheral muscle atrophy in patients with chronic respiratory failure: effects of muscle electrical stimulation. Eur Respir J 2001; 18(suppl33):488s
23 Fiatarone MA, Marks EC, Ryan ND, et al. High-intensity strength training in nonagenarians. JAMA 1990; 263:3029–3034
24 Gosselink R, Troosters T, Decramer M. Peripheral muscle weakness contributes to exercise limitation in COPD. Am J Respir Crit Care Med 1996; 153:976–980
25 Troosters T, Gosselink R, Rollier H, et al. Change in lower limb muscle strength contributes to altered six minute walking distance in COPD. Eur Respir J 1996; 9:144s
26 Debigaré R, Côté CH, Maltais F. Peripheral muscle wasting in chronic obstructive pulmonary disease: clinical relevance and mechanisms Am J Respir Crit Care Med 2001; 164:1712–1717
27 Stillwell GK, deLateur BJ, Fordice WE, et al. Physiatrics therapeutics. 2nd ed. Chicago, IL: American Academy of Physical Medicine and Rehabilitation, 1986