Respiratory Medicine (2004) **98**, 1000–1007

ELSEVIER

respiratoryMEDICINE

Heavy resistance training increases muscle size, strength and physical function in elderly male COPD-patients—a pilot study

M. Kongsgaard[a,*], V. Backer[b], K. Jørgensen[c], M. Kjær[a], N. Beyer[a]

[a]*Institute of Sports Medicine, Bispebjerg Hospital, Bispebjerg Bakke 23, Copenhagen, NV 2400 Denmark*
[b]*Respiratory Unit, Department of Internal Medicine, Bispebjerg Hospital, Copenhagen, Denmark*
[c]*Department of Human Physiology, Institute of Exercise and Sports Science, University of Copenhagen, Denmark*

Received 9 September 2003; accepted 3 March 2004

KEYWORDS
Chronic obstructive pulmonary disease;
Pulmonary rehabilitation;
Resistance training;
Muscle size;
Muscle strength;
Physical function

Summary This study investigated the effects of heavy resistance training in elderly males with chronic obstructive pulmonary disease (COPD). 18 Home-dwelling male patients (age range: 65–80 years), with a mean forced expiratory volume in the first second (FEV_1) of $46 \pm 3.4\%$ of predicted value, were recruited. Baseline and post-training assessments included: Cross-sectional area (CSA) of quadriceps assessed by MRI, isometric and isokinetic knee extension strength, isometric trunk strength, leg extension power, normal and maximal gait-speed on a 30 m track, stair climbing time, number of chair stands in 30 s, lung function (FEV_1) and self-reported health. Subjects were randomized to a resistance training group (RE, $n = 9$) or a control group conducting breathing exercises (CON, $n = 9$). RE performed heavy progressive resistance training twice a week for 12 weeks. 6 RE and 7 CON completed the study. In RE the following improved ($P < 0.05$): Quadriceps CSA: 4%, isometric knee extension strength: 14%, isokinetic knee extension strength at 60°/s.: 18%, leg extension power: 19%, maximal gait speed: 14%, stair climbing time: 17%, isometric trunk flexion: 5% and self-reported health. In CON no changes were found.

In conclusion, 12 weeks of heavy resistance training twice a week resulted in significant improvements in muscle size, knee extension strength, leg extension power, functional performance and self-reported health in elderly male COPD patients.

Introduction

It has recently been demonstrated, that peripheral muscle strength is significantly reduced in chronic obstructive pulmonary disease (COPD) patients compared with normal subjects, and that this muscle weakness to a great extent is responsible for the reduced working capacity observed in these patients.[1] This reduced peripheral muscle strength has partly been explained by a pronounced loss of muscle mass in COPD patients.[1,2] Furthermore, the inactive lifestyle and the reduced physical function are related to the reduced quality of life and greater prevalence of depression reported by COPD patients.[3,4]

Although decondition of the ambulatory muscles in COPD patients is pronounced,[5] it is only recently, that skeletal muscle dysfunction and reduced muscular strength have become a recognised sources of disability in chronic obstructive

*Corresponding author. Tel.: +45-35-316-296; fax: +45-35-312-733.
E-mail address: mads.kongsgaard@get2net.dk (M. Kongsgaard).

0954-6111/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rmed.2004.03.003

pulmonary disease.[6] Previous randomised controlled studies have shown that heavy resistance training has improved peripheral muscle force, muscle endurance and whole body endurance in COPD patients.[7–10] However, it is not clear whether these strength improvements are caused by motor-learning, neural adaptations or increases in muscle size. This knowledge would be of significance in order to optimise COPD rehabilitation.

So far, no studies have investigated if the muscle size of these patients can be improved with heavy resistance training. An increase in muscle size would seem to be of great importance in these patients because of the specific symptoms of muscle atrophy and low levels of circulating anabolic hormones.[2,11] However, a study by Bernard et al.[12] indicated, that strength training may increase muscle size in COPD patients. That study showed, that the addition of strength training to aerobic training was associated with increased thigh muscle cross-sectional area. Unfortunately that study did not have a strength training only group. Additionally, very little is known about the potential positive effects of heavy resistance training on physical function and daily living in COPD patients.

The dose–response relationship of resistance training in COPD patients has not yet been clarified. Most studies on resistance training in COPD patients have been conducted with training three times per week.[8–10] When taking in to consideration that the vast majority of COPD patients are elderly above the age of 60[6] with a low physical capacity and a low exercise tolerance[2,13] it might increase compliance, if the frequency of training is reduced to two times a week, provided that the effect of training is not substantially reduced. Thus, knowledge about muscle growth, strength and physical function in response to different doses of resistance training may contribute to optimising guidelines for COPD rehabilitation exercise programs.

Therefore, the purpose of this pilot study was to test the hypothesis, that 3 months of heavy progressive resistance training twice a week, targeted at the lower extremities, would increase muscle size, strength and physical function in elderly males with COPD. Additionally, the effect of training on the self-reported health was investigated.

Methods

Subjects

18 Home-dwelling male COPD patients (65–80 years) who were able to transport themselves to the hospital, were recruited from the respiratory outpatient clinic, Bispebjerg University Hospital, Copenhagen, Denmark. To ensure that training was not contraindicated the medical records of all subjects were analysed by a medical doctor prior to inclusion. Exclusion-criteria were: Fractures of the lower extremities within the last 6 months, neurological diseases, cardio-vascular diseases, dependence on more than one walking devise and cognitive dysfunctions. The subjects use of medication was held constant throughout the intervention period. Informed consent was obtained according to the Helsinki 2 declaration and the local ethics committee for medical research in Copenhagen approved the study protocol.

Measurements

Before and after the intervention period height and body weight were determined. The forced expiratory volume in one second (FEV_1) was measured with a 7-L dry wedge spirometer (Vitalograph®), which was calibrated daily. Each measurement consisted of at least two maximal expiratory manoeuvres from total lung capacity to residual volume with a variation of FEV_1 less than 5%. The highest FEV_1 was used in the analysis. The FEV_1 measurements for each individual were conducted at the same time of the day pre- and post-training. No physical testing or training was performed prior to the FEV_1 measurement.

The anatomical cross-sectional area (CSA) of m. quadriceps of the dominant leg was measured at mid-thigh level by magnetic resonance imaging (MRI, 1.5 T general Electric SIGNA scanner). The T1-weighted image were obtained with the following parameters: TR/TE: 400/16, FOV 12 cm, matrix 512×512 pixels and slice thickness = 6 mm. Subsequently, the lean muscle area of m. quadriceps (subcutaneous and intermuscular non-contractile tissue were not included in the measurement) of the mid-thigh image was visually outlined using the software program Web 1000 (AGFA®). The mean value of 3 measurements of the same image, was used for analysis.

All subjects conducted a series of pre-trial strength tests to familiarize themselves to the test procedure in order to reduce any learning effects.[14]

Isometric and isokinetic knee extension peak torques, of the self-reported strongest leg, were measured in a Kin-Com dynamometer (Kin-Com KC 125AP Chattanooga group, Inc. Harrison Tennessee. USA). Maximal isometric knee extension strength ($MVC_{knee\ ext}$) was measured at an angle of 60° of knee flexion (0° = fullextension).[15–17] Maximal isokinetic concentric knee extension peak torques were measured at an angular velocity of 60°/s followed by 180°/s.[18]

Dynamic strength, 5 RM (5 repetition maximum), was measured in a leg press (Horizontal seated, leg press Technogym®, Gambettolla- Italy).[19] The highest load that the subjects could lift 5 times without resting was recorded as the test-result.[20] Maximal isometric trunk extension ($MVC_{Trunk\ ext.}$) and flexion ($MVC_{Trunk\ flex.}$) peak torques were measured in the standing position.[21]

Maximal leg extension power was measured using a Nottingham Power Rig[22,23] with joint angles in the foot, knee and hip similar to those occurring when a person rises from a chair or walks up stairs.[23] Each leg was tested separately, and the maximal average power produced by either of the legs, was used for analysis.

Normal gait speed (N-gait) followed by maximal gait speed (M-gait) were measured on a 30 m track as described by Sonn et al.[25] The 30 m track approximately corresponds to the breadth of a major urban street.[24,25] The time to complete the 30 m was measured with a stopwatch, and only one trial at each speed was carried out.

Stair climbing time was measured on a staircase consisting of 13 stairs and a banister on each side. The steps were 18 cm high and 95 cm wide. The subjects were instructed to walk up the stairs as fast as possible, and were allowed to use the banister if necessary. The time was measured with a handheld stopwatch, and the best result of two trials was used for analysis.[23] Moreover, the number of chair stands that the subjects could perform in 30 s without using the arms was measured as described by Rikli and Jones.[26]

Finally, all subjects were interviewed before and after the intervention period according to a questionnaire developed by the *Danish Institute of Clinical Epidemiology*.[27] The subjects were asked if they were able to perform the following three activities of daily living (ADL) with no difficulty, with difficulty or not at all: Walk 400 m without resting, walk up or down one flight of stairs and carry 5 kg. The subjects were furthermore asked to rate their own present state of health in general (i.e. self-reported health) in one of five possible categories[27,28]: 1. Really Good, 2. Good, 3. Fair, 4. Bad or 5. Very bad.

During the post-intervention interview, the subjects were not informed about their pre-intervention ratings of ADL or self-reported health.

Training

After completion of the baseline tests the subjects were randomly allocated to either a resistance training group (RE, $n = 9$) or a control group (CON, $n = 9$). The intervention period was 12 weeks.

In RE, 60 min of supervised heavy progressive resistance training was performed twice weekly. The resistance training consisted of four sets of eight repetitions at 80% of the one-repetition maximum (1RM: the maximum load which can be lifted ones over the full range of motion) of leg press, knee extension and knee-flexion (Technogym®, Gambettolla- Italy). The conduction of each set was separated by a 2–3 min interval. The load in the different exercises was adjusted every week to ensure that the relative load was constant. Moreover, the subjects were instructed to perform the concentric phase in each exercise as explosively as possible. In case of non-attendance from one or more training sessions, the training period was extended until a total of 24 training sessions had been completed. This specific training-form, and the training period, was based on previous successful studies on heavy resistance training in elderly.[29–31]

In CON the subjects were instructed to perform non-supervised daily breathing exercises including exercises with PEP-flutes (PEP = positive expiratory pressure). This exercise program was the standard maintenance program given to COPD patients at the hospital. Furthermore, these breathing exercises were considered to eliminate any Hawthorne effect between the two groups, but not to affect neither muscle strength nor muscle size.

Statistical analysis

All data are presented as group means ± standard error of the mean (SE). To compare the groups on inclusion, the Mann–Whitney test was used. Pre- to post-training changes were evaluated by using the Wilcoxon signed rank test for paired samples. To determine the time by group effect, the delta values, i.e. the relative changes normalized to baseline values, were compared using the Mann–Whitney test. Spearman's rho (r_s) was determined to test the presence of any rank–order association between variables. Based on a hypothesis of a relationship between changes in strength and power and changes in physical function, correlation analyses were carried out using the delta values for each of the variables. Analyses of the correlations between delta values for each of the variables, were justified by the fact, that no significant differences existed between the groups on inclusion. All test were carried out as two-tailed with a chosen significance level of 0.05. The statistical analyses of the data were performed using the statistical software package SPSS® for Windows version 10.0.5 (1999).

Results

Results are reported for the six RE and the seven CON who completed the study. Characteristics of the two groups are shown in Table 1. No significant differences existed between the groups on inclusion in any of the measured parameters. Five subjects, three from the RE and two from the CON, withdrew from the study due to reasons not related to the intervention (lack of motivation and time expenditure). These subjects did not differ from those who completed the study in any of the measured parameters at baseline. As shown in Table 1, no significant changes occurred over time in either of the groups regarding the anthropometric parameters. FEV_1 tended to decrease over time in CON ($P = 0.058$) and was unchanged in RE.

While most of the measured parameters improved as a result of heavy resistance training, no changes were found in the control group (Table 2).

At 3 months the self-reported ADL level was significantly higher in RE than in CON regarding walking 400 m ($P<0.05$), climbing stairs ($P<0.05$) and carrying 5 kg ($P<0.05$). Self-reported health improved significantly from pre to post in RE ($P<0.05$), and was significantly better than in CON at 3 months ($P<0.05$). No changes in ADL or self-reported health were found in CON.

A number of significant relationships between changes in strength, physical function and power was found (Table 3).

Discussion

The primary findings of this study were, that a basic heavy resistance training program targeted at the lower extremities, resulted in significant improvements in muscle size, muscle strength, power, functional performance, self-reported ADL and self-reported health in elderly males suffering from a moderate to severe degree of COPD. Thus, the present study is the first to show that heavy resistance training can improve muscle mass (CSA), physical function and self-reported health in elderly COPD patients. Additionally, the present study confirms the findings from previous studies, that heavy resistance training can improve strength in COPD patients.[8–10] The patients in the present study were in general unselected regarding co-morbidity although patients with cardiological and neurological diseases were excluded. Thus we believe, that the present study population is fairly representative for the group of elderly male COPD patients.

At baseline, subjects in the present study had considerably smaller quadriceps CSA (approximately 15%) than found in sedentary healthy elderly males of equal age.[19,32,33] This finding is supported by Bernard et al.[34] However, the increase in quadriceps CSA at mid-thigh level found in the RE subjects in the present study (on average 4.2%), is similar to the improvements found in previous studies investigating the effects of heavy resistance training in healthy elderly.[19,29,31,35,36]

At baseline the maximal isometric and isokinetic knee extension strength in RE and CON was approximately 55% lower than values found in healthy elderly men.[16,18,37] These findings are supported by previous studies that have compared elderly male COPD patients with healthy sedentary elderly men.[1,2,34] Three months of heavy resistance training in the present study produced significant improvements in isometric knee extension strength (15%) and isokinetic knee extension strength at 60°/s (18%). The improvement in isometric strength is in accordance with the 25% and 20% increase in isometric knee extension torque found by Simpson

Table 1 Characteristics of the two groups. Mean values ± SE.

	RE ($n = 6$)		CON ($n = 7$)	
	Pre	Post	Pre	Post
Age (years)	71 ± 1.3		73 ± 1.8	
Body weight (kg)	74 ± 3.9	73 ± 3.3	81 ± 4.3	81 ± 4.5
Height (cm)	173 ± 2.6	174 ± 2.7	176 ± 1.5	176 ± 1.4
FEV_1 (l/s)	1.58 ± 0.25	1.53 ± 0.18	1.39 ± 0.14	1.24 ± 0.11
FEV_1% pred.	48 ± 4.4		44 ± 2.6	
FEV_1/FVC (%)	53 ± 1.9		54 ± 2.9	

FEV_1 = Forced expiratory volume in one second.
FEV_1% pred. = % forced expiratory volume in one second of predicted value.
RE = The group who performed resistance exercise. Con = control group.

Table 2 Results from mid-thigh quadriceps CSA, strength measurements, leg extension power and 30 m maximal gait time. Mean values ± SE.

	RE ($n = 6$)			CON ($n = 7$)		
	Pre	Post	Difference	Pre	Post	Difference
CSA (mm^2)	5390 ± 360	5614 ± 396*	224 ± 112 (+4.2%)	5637 ± 516	5618 ± 565	−18 + 59
$MVC_{knee\ ext}$ (Nm)	87 ± 10.7	100 ± 11.1*,†	13 ± 2.0 (+14.7%)		71 ± 15.2	−5 ± 5.4
Knee ext. 60°/s (Nm)	65 ± 8.0	76 ± 8.2*,†	12 ± 3.0 (+17.8%)	71 ± 9.9	65 ± 8.2	−6 ± 4.7
Knee ext. 180°/s (Nm)	53 ± 5.0	61 ± 7.0†	8 ± 4.4	55 ± 7.6	51 ± 6.5	−5 ± 2.2
5RM (kg)	168 ± 16.2	228 ± 23.0*,‡	60 ± 11.9 (+36.5%)	146 ± 15.2	140 ± 15.2	−6 ± 3.0
Trunk ext. 0°s/ (Nm)	133 ± 9.8	143 ± 7.0	10 ± 4.6	128 ± 21.6	131 ± 19.9	3 ± 4.2
Trunk flex. 0°/s (Nm)	140 ± 11.3	147 ± 11.3*	7 ± 0.2 (+5.2%)	152 ± 30.5	153 ± 30.8	1 ± 2.9
Power (W/kg)	1.97 ± 0.25	2.30 ± 0.27*,†	0.30 ± 0.04 (+18.8%)	1.89 ± 0.24	1.61 ± 0.30	−0.27 ± 0.21
M-Gait (s)	19.3 ± 1.9	16.5 ± 2.3*,‡	−2.8 ± 0.8 (−14.4%)	24.8 ± 3.5	26.4 ± 4.0	1.6 ± 1.7
N-Gait (s)	25.5 ± 2.8	26.3 ± 3.4	0.8 ± 1.2	33.6 ± 3.8	36.3 ± 3.3	2.7 ± 1.4
Stair (s)	4.7 ± 0.6	3.9 ± 0.4*	−0.8 ± 0.2 (−17.2%)	8.7 ± 1.81	8.4 ± 1.6	−0.2 ± 0.6
Chair (number)	17.0 ± 2.1	18.3 ± 2.7	1.3 ± 2.3	9.7 ± 2.5	8.4 ± 1.5	−1.3 ± 1.1

Significantly different from pre-value, $^{*}P<0.05$. Significant time by group effect.
$^{\dagger}P<0.05$.
$^{\ddagger}P<0.01$. 5RM = Five repetition maximum; Ext = Extension; Flex = Flexion; Nm = Newton meter; W = Watt. M-gait = Maximal gait time 30 m; N-gait = Normal gait time 30 m; Stair = Stair climbing time; Chair = Number of chair stands in 30 s.

Table 3 Significant relationship between changes in strength, power and physical function.

$n = 13$	ΔPower	ΔM-Gait	ΔStair	ΔChair	Δ5RM	$\Delta MVC_{knee\ ext.}$	ΔKE-60
ΔPower							
ΔM-Gait	$r_s = -0.857$ $P = 0.001$						
ΔStair							
ΔChair	$r_s = -0.630$ $P = 0.21$	$r_s = -0.705$ $P = 0.007$					
Δ5RM	$r_s = 0.929$ $P = 0.002$	$r_s = -0.852$ $P = 0.038$		$r_s = 0.606$ $P = 0.028$			
$\Delta MVC_{knee\ ext.}$	$r_s = 0.824$ $P = 0.001$	$r_s = -0.560$ $P = 0.001$			$r_s = 0.869$ $P = 0.001$		
ΔKE-60	$r_s = 0.634$ $P = 0.020$	$r_s = -0.714$ $P = 0.006$			$r_s = 0.693$ $P = 0.09$	$r_s = 0.647$ $P = 0.017$	
ΔKE-180	$r_s = 0.651$ $P = 0.016$	$r_s = -0.727$ $P = 0.005$			$r_s = 0.636$ $P = 0.019$		$r_s = 0.877$ $P<0.001$

r_s = Spearmans rho (2-tailed). P = Level of significance. Power = Leg extension power; Δ = Difference between pre- and post-values; M-gait = Maximal gait time; Stair = Stair climbing time; Chair = Number of chair stands in 30 s; 5RM = Five repetition maximum; $MVC_{knee\ ext.}$ = Maximal voluntary contraction of knee extension; KE-60 = Knee extension at 60°/s; KE-180 = Knee extension at 180°/s; The pooled changes for the two groups were used in the correlation analysis.

et al.[8] and Spruit et al.[9] respectively. However, these studies applied resistance training three times a week, whereas the subjects in the present study only trained twice a week. Additionally, the 37% increase in 5-RM strength in RE in the present study, is in accordance with the 44% increase in 1

RM leg extension found in elderly COPD patients by Simpson et al.[8] but somewhat lower than the 52% improvement in 1 RM strength reported by Ortega et al.[10] The relative great improvements in 1 RM strength reported by Ortega et al.[10] may be explained by learning effects due to the absence of familiarisation pre-trials, which are normally considered as a gold standard when testing strength.

The relative improvement of 19% in leg extension power is identical to the improvements found by Skelton et al.[38] who investigated the effect of 12 weeks of resistance training in 20 healthy elderly women. At baseline, an average leg extension power of 1.97 ± 0.2 W/kg was found in RE. In comparison Pearson et al.[39] found an average leg extension power corresponding to 2.8 ± 0.2 W/kg in 13 elderly sedentary healthy men (age 70–79). Thus, it appears that on inclusion, the subjects in the present study had a lower leg extension power than healthy elderly men of equal age. Therefore, the improvements in leg extension power found in the present study could potentially be of great functional importance, since there is a positive relationship between changes in leg extension power and changes in functional performance in the present study (see Table 3), and in a previous study of elderly subjects.[23] In the present study a 14% improvement in maximal gait speed and a 17% improvement in stair climbing speed were found in RE. These improvements are in accordance with Fiatarone et al.[35] who demonstrated a 12% increase in gait velocity and a 28% increase in stair climbing power following 10 weeks of resistance training in 72–98 year old nursing home residents. On inclusion, time to walk 30 m at maximal speed was somewhat longer in our subjects (19.3 ± 1.92 s) compared with 70 year old healthy men (16.7 ± 3.7).[25] However, after training this difference did not exist.

In the present study, the significant relationship between changes in strength, power and physical function indicates that a substantial part of the improvements in physical function, can be attributed to the improved level of strength and power as a result of resistance training. In support of the findings in the present study, Gosselink et al. and Bernard et al. have suggested that peripheral muscle weakness is an equally important determinant of exercise capacity in COPD patients as lung function.[34,40] Thus, the present study indicates, that even though elderly male COPD patients have a low physical function, heavy resistance training can improve their physical function significantly, approaching the levels of sedentary age-matched subjects. Moreover, it is interesting and encouraging to note, that the self-reported ADL level after training was significantly higher in RE than in CON regarding walking 400 m, climbing stairs and carrying 5 kg. Furthermore, and maybe most important, the self-reported health improved significantly from pre to post in RE. This would seem to be of great significance, since it has been shown, that the health-related quality of life is severely impaired in COPD patients.[41] This finding is supported by previous studies that have found an improved health-related quality of life (HRQL) following resistance training in COPD patients.[9,10]

In the present study, patients who performed breathing exercises only, showed a numeric reduction in FEV_1 over the 12 week period ($P = 0.058$), whereas the FEV_1 was unchanged in the resistance training group. The present groups are too small to make any conclusion regarding a relationship between resistance training and maintenance of lung function. This potential relationship is however of interest, since two previous studies by Simpson et al.[8] and Wright et al.[42] have also found positive trends toward an improved pulmonary function following a period of heavy resistance training. In contrast, no significant changes in pulmonary function was found by Ortega et al.[10] as a result of strength training in their group of elderly COPD patients. Therefore, more and larger studies are needed to answer this very important question.

In conclusion, 12 weeks of heavy resistance training twice a week was well tolerated by these relatively frail elderly COPD patients, and produced significant and relevant improvements in muscle strength, leg extension power and functional performance, indicating that resistance training may translate into better daily living in COPD patients. Furthermore, the present study is the first to show that muscle size can improve in elderly COPD patients in response to resistance training. Finally, self-reported health improved, indicating that heavy resistance training may have a positive effect on quality of life in elderly COPD patients. However, the study sample was small and therefore the study protocol needs to be replicated in a larger sample before the results can be generalized to all elderly COPD patients.

References

1. Hamilton AL, Killian KJ, Summers E, Jones NL. Muscle strength, symptom intensity, and exercise capacity in patients with cardiorespiratory disorders. *Am J Respir Crit Care Med* 1995;**152**:2021–31.

2. Storer TW. Exercise in chronic pulmonary disease: resistance exercise prescription. *Med Sci Sports Exerc* 2001;**33**: S680–92.
3. Finnerty JP, Keeping I, Bullough I, Jones J. The effectiveness of outpatient pulmonary rehabilitation in chronic lung disease: a randomized controlled trial. *Chest* 2001;**119**: 1705–10.
4. Sturesson M, Inga-Britt B. Life satisfaction in subjects with chronic obstructive pulmonary disease. *Work* 2000;**14**: 77–82.
5. Cooper CB. Exercise in chronic pulmonary disease: limitations and rehabilitation. *Med Sci Sports Exercise* 2001;**33**:643–6.
6. Casaburi R. Skeletal muscle dysfunction in chronic obstructive pulmonary disease. *Med Sci Sports Exerc* 2001;**33**: S662–70.
7. Clark CJ, Cochrane LM, Mackay E, Paton B. Skeletal muscle strength and endurance in patients with mild COPD and the effects of weight training. *Eur Respir J* 2000;**15**:92–7.
8. Simpson K, Killian K, McCartney N, Stubbing DG, Jones NL. Randomised controlled trial of weightlifting exercise in patients with chronic airflow limitation. *Thorax* 1992;**47**: 70–5.
9. Spruit MA, Gosselin R, Troosters T, De Paepe K, Decramer M. Resistance versus endurance training in patients with COPD and peripheral muscle weakness. *Eur Respir J* 2002;**19**: 1072–8.
10. Ortega F, Toral J, Cejudo P, Villagomez R, Sanchez H, Castillo J, Montemayor T. Comparison of effects of strength and endurance training in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2002;**166**: 669–74.
11. Casaburi R, Goren S, Bhasin S. Substantial prevalence of low anabolic hormone levels in COPD patients undergoing rehabilitation. *Am J Respir Crit Care Med* 1996;**153**: A128.
12. Bernard S, Whittom F, LeBlanc P, Jobin J, Belleau R, Berube C, Carrier G, Maltais F. Aerobic and strength training in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1999;**159**:896–901.
13. Maltais F, LeBlanc P, Simard C, Jobin J, Berube C, Bruneau J, Carrier L, Belleau R. Skeletal muscle adaptation to endurance training in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1996;**154**: 442–7.
14. Frontera WR, Hughes VA, Dallal GE, Evans WJ. Reliability of isokinetic muscle strength testing in 45- to 78-year-old men and women. *Arch Phys Med Rehabil JID - 2985158R* 1993;**74**: 1181–5.
15. Narici MV, Landoni L, Minetti AE. Assessment of human knee extensor muscles stress from in vivo physiological cross-sectional area and strength measurements. *Eur J Appl Physiol Occup Physiol* 1992;**65**:438–44.
16. Horstmann T, Maschmann J, Mayer F, Heitkamp HC, Handel M, Dickhuth HH. The influence of age on isokinetic torque of the upper and lower leg musculature in sedentary men. *Int J Sports Med JID - 8008349* 1999;**20**:362–7.
17. Kues JM, Rothstein JM, Lamb RL. Obtaining reliable measurements of knee extensor torque produced during maximal voluntary contractions: an experimental investigation. *Phys Ther* 1992;**72**:492–504.
18. Aniansson A, Sperling L, Rundgren A, Lehnberg E. Muscle function in 75-year-old men and women. A longitudinal study. *Scand J Rehabil Med* 1983;**9**(Suppl):92–102.
19. Tracy BL, Ivey FM, Hurlbut D, Martel GF, Lemmer JT, Siegel EL, Metter EJ, Fozard JL, Fleg JL, Hurley BF. Muscle quality. II. Effects of strength training in 65–75-yr-old men and women. *J Appl Physiol* 1999;**86**:195–201.
20. Esmarck B, Andersen JL, Olsen S, Richter EA, Mizuno M, Kjær M. Timing of postexercise protein intake is important for muscle hypertrophy with resistance training in elderly humans. *J Physiol* 2001;**535**:301–11.
21. Essendrop M, Schibye BHK. Reliability of isometric muscle strength test for the trunk, hands and shoulders. *Int J Ind Ergonomics* 2001;**28**:379–87.
22. Bassey EJ, Short AH. A new method for measuring power output in a single leg extension: feasibility, reliability and validity. *Eur J Appl Physiol Occup Physiol* 1990;**60**:385–90.
23. Bassey EJ, Fiatarone MA, O'Neill EF, Kelly M, Evans WJ, Lipsitz LA. Leg extensor power and functional performance in very old men and women. *Clin Sci (Colch)* 1992;**82**:321–7.
24. Aniansson A, Rundgren A, Sperling L. Evaluation of functional capacity in activities of daily living in 70-year-old men and women. *Scand J Rehabil Med* 1980;**12**:145–54.
25. Sonn U, Frandin K, Grimby G. Instrumental activities of daily living related to impairments and functional limitations in 70-year-olds and changes between 70 and 76 years of age. *Scand J Rehabil Med JID - 0212503* 1995;**27**:119–28.
26. Rikli RE, Jones JC. Senior fitness test manual. Human kinetics, U.S.A; 2001.
27. Kjøller M, Rasmussen NK, Keiding HC, Nielsen GA. Sundhed og sygelighed i Danmark 1994. 1995. Dansk Institut for klinisk epidemiologi. Homepage: www.dike.dk.
28. Idler EL, Benyamini Y. Self-rated health and mortality: a review of twenty-seven community studies. *J Health Soc Behav* 1997;**38**:21–37.
29. Frontera WR, Meredith CN, O'Reilly KP, Knuttgen HG, Evans WJ. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J Appl Physiol* 1988;**64**: 1038–44.
30. Porter MM, Vandervoort AA, Lexell J. Aging of human muscle: structure, function and adaptability. *Scand J Med Sci Sports* 1995;**5**:129–42.
31. Harridge SD, Kryger A, Stensgaard A. Knee extensor strength, activation, and size in very elderly people following strength training. *Muscle Nerve* 1999;**22**:831–9.
32. Klitgaard H, Mantoni M, Schiaffino S, Ausoni S, Gorza L, Laurent-Winter C, Schnohr P, Saltin B. Function, morphology and protein expression of ageing skeletal muscle: a cross-sectional study of elderly men with different training backgrounds. *Acta Physiol Scand* 1990;**140**:41–54.
33. Frontera WR, Hughes VA, Fielding RA, Fiatarone MA, Evans WJ, Roubenoff R. Aging of skeletal muscle: a 12-yr longitudinal study. *J Appl Physiol JID - 8502536* 2000;**88**:1321–6.
34. Bernard S, LeBlanc P, Whittom F, Carrier G, Jobin J, Belleau R, Maltais F. Peripheral muscle weakness in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 1998;**158**:629–34.
35. Fiatarone MA, O'Neill EF, Ryan ND, Clements KM, Solares GR, Nelson ME, Roberts SB, Kehayias JJ, Lipsitz LA, Evans WJ. Exercise training and nutritional supplementation for physical frailty in very elderly people. *N Engl J Med* 1994;**330**:1769–75.
36. Kryger AI. Effects of resistance training on skeletal muscle and function in the oldest old. Denmark: University of Copenhagen; 1998.
37. Frontera WR, Hughes VA, Lutz KJ, Evans WJ. A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women. *J Appl Physiol JID - 8502536* 1991;**71**: 644–50.
38. Skelton DA, Young A, Greig CA, Malbut KE. Effects of resistance training on strength, power, and selected

functional abilities of women aged 75 and older. *J Am Geriatr Soc JID - 7503062* 1995;**43**:1081–7.
39. Pearson SJ, Young A, Macaluso A, Devito G, Nimmo MA, Cobbold M, Harridge SD. Muscle function in elite master weightlifters. *Med Sci Sports Exerc* 2002;**34**:1199–206.
40. Gosselink R, Troosters T, Decramer M. Peripheral muscle weakness contributes to exercise limitation in COPD. *Am J Respir Crit Care Med* 1996;**153**:976–80.
41. Lisboa C, Villafranca C, Caiozzi G, Berrocal C, Leiva A, Pinochet R, Borzone G, Diaz O. Quality of life in patients with chronic obstructive pulmonary disease and the impact of physical training. *Rev Med Chil* 2001;**129**:359–66.
42. Wright PR, Heck H, Langenkamp H, Franz KH, Weber U. Influence of a resistance training on pulmonary function and performance measures of patients with COPD. *Pneumologie* 2002;**56**:413–7.