Original articles

Body composition and exercise performance in patients with chronic obstructive pulmonary disease

A M W J Schols, R Mostert, P B Soeters, E F M Wouters

Abstract

To investigate whether a compromised nutritional state may limit exercise performance in patients with chronic obstructive pulmonary disease we studied 54 such patients (FEV_1 < 50% and arterial oxygen tension (PaO_2) > 7·3 kPa) whose clinical condition was stable and who were admitted to a pulmonary rehabilitation centre. Fat free mass was assessed anthropometrically (from skinfold measurements at four sites) and by bioelectrical impedance; creatinine height index and arm muscle circumference were also assessed. The mean (SD) distance walked in 12 minutes was 845 (178) m. No association was established between the distance walked and spirometric measures. A good correlation was found between the distance walked and fat free mass in the whole group (r = 0·73 for impedance measurements and 0·65 for skinfold thickness) and in a subgroup of 23 lean patients (body weight <90% of ideal weight; r = 0·66 for impedance measurements and 0·46 for skinfold thickness). Body weight correlated with the distance walked only in the whole group (r = 0·61). On stepwise regression analysis fat free mass measured by bioelectrical impedance, maximal inspiratory mouth pressure, and PaO_2 accounted for 60% of the variation in the distance walked in 12 minutes. We conclude that fat free mass, independently of airflow obstruction, is an important determinant of exercise performance in patients with severe chronic obstructive pulmonary disease.

Departments of Pulmonary Diseases and Surgery, University of Limburg, Maastricht, The Netherlands
A M W J Schols
P B Soeters
E F M Wouters

Asthma Centre "Hornerheide", Horn, The Netherlands
R Mostert

Reprint requests to: Dr A M W J Schols, Department of Pulmonary Diseases, University Hospital Maastricht, PO Box 5800, 6202 AZ Maastricht, The Netherlands

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Patients with chronic obstructive pulmonary disease may be severely disabled by dyspnoea and show impairment on exercise. Cotes *et al* showed that in patients whose exercise capacity was limited by respiratory factors the limitation could not be predicted accurately by FEV_1, forced vital capacity, and carbon monoxide transfer factor; prediction of Vo_2max was improved by taking age, fat free mass, and submaximal exercise ventilation into account.[1] Several studies have explored whether a compromised nutritional state may contribute to a reduced exercise performance in patients with chronic obstructive pulmonary disease,[2-6] and a positive association between nutritional state (measured by body weight as a percentage of ideal weight) and maximal exercise performance has been found in some.[2-4] Two studies, however, found no difference in submaximal exercise performance measured by a six minute walking test between underweight (body weight <90% of ideal weight) and normal weight patients.[2 5]

Body weight or body weight corrected for height as a measure of nutritional state is commonly used in clinical studies but has been criticised because it does not take differences in body composition between people into account.[6] When we studied the relation between the distance walked in 12 minutes and other nutritional measures in addition to body weight walking distance was positively associated with serum albumin concentration and creatinine height index but not with body weight as a percentage of ideal body weight.[7]

This study had two aims: firstly, to compare standard measurements of body composition with a comparatively new technique using bioelectrical impedance and, secondly, to explore the relation between these body composition measures and submaximal exercise performance in a selected group of patients with stable chronic obstructive pulmonary disease.

Methods

PATIENTS

Fifty four patients with chronic obstructive pulmonary disease admitted to an inpatient pulmonary rehabilitation centre for exercise training were studied. All patients had severe airflow obstruction (FEV_1 < 50% of predicted values) and an arterial oxygen tension (PaO_2) > 7·3 kPa. Patients with cardiovascular, neurological, endocrine, or locomotor disease or who were obese (body weight > 120% of ideal weight) were excluded from exercise testing. None of the patients had a respiratory tract infection or oedema at the time of the study. Maintenance treatment in all patients included theophylline, $beta_2$ agonists, and inhaled or oral corticosteroids.

LUNG FUNCTION

FEV_1 and inspiratory vital capacity were measured with a wet spirometer; the highest value from at least three spirometric manoeuvres was expressed as a percentage of predicted values.[8] Blood was drawn by puncture of the brachial artery at rest while the patient was breathing room air. Pao_2 and arterial carbon dioxide tension ($Paco_2$) were measured with a blood gas analyser (Radiometer ABL 330, Copenhagen, Denmark). Inspiratory muscle strength was assessed by determining maximal inspiratory mouth pressures according to the technique described by Black and Hyatt, the best of three determinations being used in subsequent calculations.[9]

BODY COMPOSITION

Because there is no single generally accepted, non-invasive measure of body composition several methods were used and compared. Body height to the nearest 0·5 cm was measured with a stadiometer with head traction and correct posturing (Lameris WM 715, Breukelen, The Netherlands) when subjects were standing barefoot. Body weight to the nearest 0·1 kg was measured with a calibrated beam scale (SECA, Federal Republic of Germany) when subjects were standing barefoot in light clothing. Frame size (small, medium, or large) was calculated from wrist circumference. Body weight was expressed as a percentage of ideal weight (the midpoint of the weight range for a given height and frame size[10]). Mid-upper arm circumference of the right arm was measured with a flexible measuring tape.[11] Skinfold thickness was measured in triplicate with a skinfold calliper.[12] All anthropometric measurements were performed by the same research assistant. Arm muscle circumference was derived by subtracting $\pi \times$ the triceps skinfold thickness (mm) from the midarm circumference.[13] Arm muscle circumferences were expressed as a percentage of standard values for age and sex.[11,13] Body fat content was estimated from the sum of skinfold thicknesses at four sites (bicipital, tricipital, subscapular and suprailiac) according to the tables of Durnin and Womersley.[14] Fat free mass was calculated by subtracting the fat content from body weight. Skeletal muscle mass was estimated from the creatinine height index, calculated by dividing 24 hour urinary creatinine excretion by a reference value based on ideal body weight.[15]

Body composition was also assessed by the bioelectrical impedance method, whose principle is based on the conductance of an electrical sinusoidal alternating current through body fluids.[16] Conductivity is higher in the fat free mass, which contains all body fluids and electrolytes, than in fat. Theoretically, fat free mass is linearly related to $(\text{body height})^2/\text{impedance}$ or $(\text{height})^2/\text{resistance}$.[17] Resistance was measured, with subjects supine, at the right site as described by Lukaski *et al* (BIA 101, RJL Systems, Detroit, Michigan).[18] Fat free mass was calculated with a patient specific regression equation (independent variables: $(\text{height})^2/\text{resistance}$ and body weight)[19] derived from a previous study in which we compared body composition by bioelectrical impedance with deuterium dilution as a reference method in patients with stable chronic obstructive pulmonary disease.[20] As no data are available on ideal fat free mass, fat free mass was expressed as a percentage of ideal body weight.

EXERCISE PERFORMANCE

Exercise performance was assessed from a 12 minute walking test performed on a level enclosed corridor as described by McGavin *et al* and used previously in patients with chronic obstructive pulmonary disease.[21,22] All tests were performed in the early afternoon and no encouragement was given. The patients performed one practice test.[22,23] The distance covered after two, six, and 12 minutes' walking was measured. Patients who were not able to walk continuously for 12 minutes were excluded from the analysis.

STATISTICAL ANALYSES

Descriptive statistics are given as means (SD). Body composition measures were correlated with each other, with lung function measures, and with the distance walked in 12 minutes by means of the product moment correlation coefficient.[24] After the simple correlations had been completed a linear model was fitted to the data to enable the variables that contributed to the distance walked to be determined by stepwise regression analysis.[25]

Results

Table 1 summarises the characteristics of the study group of 54 patients with chronic obstructive pulmonary disease. Most of the group were men (80%) and their ages were normally distributed, ranging from 50 to 79. Most patients were normal or underweight when body weight was expressed as a percentage of ideal weight (range 69·3–120·0%). Fat free mass values by bioelectrical impedance were significantly lower than by skinfold anthropometry ($p < 0.001$). Highly significant correlations were obtained between the independent measures of body composition (table 2). A good correlation ($r = 0.86$) was found between the two measures of fat free

Table 1 Characteristics of study group

Characteristic	*Mean (SD)*
Age (years)	66·0 (6·0)
Inspiratory vital capacity:	
l	2·5 (0·7)
%	67·0 (19·0)
FEV_1:	
l	0·9 (0·3)
%	33·0 (9·0)
Arterial gas tension (kPa):	
Oxygen	9·7 (1·4)
Carbon dioxide	5·3 (0·6)
Maximal inspiratory pressure (kPa)	5·8 (2·3)
Body weight (% ideal weight)	95·4 (13·4)
Fat free mass (% ideal weight):	
Biochemical impedance	70·7 (8·5)
Skinfold anthropometry	75·9 (9·5)
Creatinine height index (%)	73·7 (19·4)
Arm muscle circumference (%)	90·2 (9·2)

Table 2 Mutual correlation coefficients of the body composition measures

	Fat free mass (% ideal weight)		*Creatinine height index (%)*	*Arm muscle circumference (%)*
	Bioelectrical impedance	*Skinfold anthropometry*		
Body weight (% ideal weight)	0·79	0·81	0·49	0·69
Fat free mass (% ideal weight):				
Biochemical impedance		0·86	0·54	0·51
Skinfold anthropometry			0·46	0·41
Creatinine height index (%)				0·44

All values are significant ($p < 0·001$).

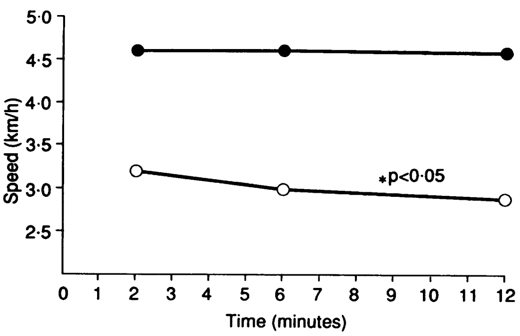
mass; this was slightly higher than the correlation between either measure of fat free mass and body weight. Creatinine height index correlated slightly better with fat free mass values by bioelectrical impedance than with those from skinfold anthropometry or with body weight. Arm muscle circumference correlated less with the other measures except for body weight. Maximal inspiratory mouth pressure correlated significantly with body weight ($r = 0·35$, $p < 0·005$), fat free mass ($r = 0·30$, $p = 0·01$), and creatinine height index ($r = 0·32$, $p < 0·01$). No significant associations were found between any of the nutritional measures and inspiratory vital capacity, FEV_1, or arterial blood gas tensions.

Exercise performance

The mean distance covered in 12 minutes' walking was 845 (178) m. The mean increase between practice and experimental test was 119 m (95% confidence interval 76 to 162 m). Walking speed (km/h) after 2, 6, and 12 minutes' walking was compared in the low performance group (distance walked more than one SD below the mean distance walked) and the other patients (figure). Mean walking speed after 2 minutes' walking was 4·6 km/h in the patients with normal to high performance and did not change throughout the test. Mean walking speed in the low performance group was 3·2 km/h after 2 minutes and lower for the remainder of the test ($p < 0·05$). The mean increase in heart rate at the end of the test was 28 (15) beats/min and did not differ between the two groups.

Relation of walking distance to other variables

The distance covered in 12 minutes' walking showed significant positive correlations with all body composition measures. A good correlation was found between the distance walked and fat free mass determined by bioelectrical impedance (table 3). Among the lung function measurements only maximal inspiratory mouth pressure and Pao_2 significantly correlated with the distance walked. In a subgroup of underweight patients (body weight < 90% of ideal weight, $n = 23$; table 3) the correlation with body weight disappeared, but the correlation between fat free mass and the distance walked remained highly significant. In the multiple regression model fat free mass by bioelectrical impedance, maximal inspiratory mouth pressure and Pao_2 accounted for 60% of the variation in the distance covered (table 4). Although the distance covered differed significantly between men and women, sex was not significant in the stepwise regression analysis.



Mean walking speed after 2, 6, and 12 minutes' walking in the low performance group (distance walked > 1 SD below the mean distance walked) (○——○) and in the other patients (●——●).

Discussion

The few published studies report conflicting results on the relation between nutritional state and exercise performance. Studies measuring maximal exercise performance by cycle ergometry have established a positive association between maximal oxygen consumption ($\dot{V}o_2$ max) and body weight as a percentage of ideal weight. Contrary to other studies,[2 5 7] we found a significant positive association between submaximal exercise performance in a walking test and body weight. The differences in outcome of these studies might be related to several factors, including the type of exercise test, the selection of patients, and the nutritional measures studied.

Table 3 Correlation coefficients for body composition measures and lung function with distance covered in 12 minutes' walking

	Total group (n = 54)	*Subgroup (n = 23)**
Inspiratory vital capacity:		
l	0·22	0·30
%	0·04	0·05
FEV_1:		
l	0·06	0·05
%	0·01	0·03
Arterial gas tension (kPa):		
Oxygen	0·28†	0·05
Carbon dioxide	0·07	0·10
Maximal inspiratory pressure (kPa)	0·41‡	0·27
Body weight (% ideal weight)	0·61‡	0·18
Fat free mass (% ideal weight):		
Bioelectrical impedance	0·73‡	0·66‡
Skinfold anthropometry	0·65‡	0·46†
Creatinine height index (%)	0·39‡	0·21
Arm muscle circumference (%)	0·37‡	0·07

*Body weight <90% of ideal weight.
†$p < 0·05$; ‡$p < 0·001$.

Table 4 Selected prediction equation with walking distance as dependent variable

Prediction variable	Regression coefficient	R^2 model*	F model†	Df	Student's t test‡	p value
Fat free mass (bioelectrical impedance)	13·80	0·52	58·0	1·53	7·08	<0·001
Maximal inspiratory mouth pressure	1·94	0·56	33·5	2·52	2·52	<0·01
Arterial oxygen tension	27·54	0·60	26·6	3·51	2·45	<0·05

Intercept −514·52.
*R^2 = (regression sum of squares)/(total sum of squares) for model consisting of current and preceding variables.
†Consisting of current and preceding variables.
‡After adjustment of the remaining variables.

In contrast to other studies[2 5] we used a 12 minute walking test, which may be more discriminatory than a six minute test. The figure shows that in the patients with the poorest performance walking speed decreased between 6 and 12 minutes' walking. Nevertheless, the positive association with body weight remained when we used a six instead of a 12 minute walking test. Obesity[26] may explain why the distance walked by normal weight patients (mean 118% (17%) of ideal body weight) was not different from that walked by underweight patients in the study by Efthimiou *et al*.[5]

Although we found a good correlation between body weight and the distance walked, the correlation coefficient between fat free mass and walking distance was better. The increased value of fat free mass over body weight was most pronounced, however, in the subgroup of underweight patients. This indicates that only when fat free mass drops to very low values is it critical for physical performance.

We compared fat free mass with commonly used clinical measures of body composition. Creatinine height index correlated reasonably well with fat free mass, although urinary creatinine excretion varies substantially from day to day, which detracts from its usefulness as an indicator of muscle mass.[7] Arm muscle circumference added little to the estimation of muscle mass; it correlated less well with creatinine height index and fat free mass than with body weight. A disadvantage of skinfold anthropometry is that the method assumes that a constant proportion of total body fat is subcutaneous. Fat mass is, however, underestimated in elderly subjects owing to a centralisation and internalisation of body fat that is not reflected by skinfold thickness.[27 28] This variability may be reflected more in arm muscle circumference, which is based on a measurement of skinfold thickness at one site, than in fat free mass by anthropometry, which is based on skinfold thickness measurements at four sites.

In spite of these problems, stepwise regression analysis showed that the fat free mass estimated by bioelectrical impedance contributed the major part of the explained variation in the distance covered in 12 minutes' walking.

Muscle wasting is an obvious part of depletion of fat free mass. In general, the strength of skeletal muscle is related to muscle mass and muscle fibre contractility. The respiratory muscles like other striated muscles contain a mixture of type I or slow twitch (oxygen dependent, fatigue resistant) fibres and type II or fast twitch (dependent on oxidative (IIa) or glycolytic (IIb) energy stores).[29] Slow twitch fibres are recruited during low intensity contractions. As the intensity of contraction increases, fast twitch fatigue resistant and later fast twitch fatiguable fibres are recruited.

In various animal models prolonged undernutrition is associated with proportional reductions in diaphragmatic mass as a result of decreases in cross sectional area of the muscle fibre.[30-32] The reduction in muscle bulk results in a decrease in muscle force, while the mechanical effectiveness of the residual myofibrillar material is unaffected. The effect of undernutrition on fast fibres is greater than that on slow fibres: greater atrophy of fast fibres ensures that a greater percentage of the total muscle cross sectional area will be composed of slow oxidative fibres, whose resistance to fatigue is greater than that of fast fibres. The tension of the respiratory muscles generated during basal activities may therefore be preserved, but the maximum power output of the diaphragm in wasted subjects will be impaired as progressively greater numbers of fast fibres must be recruited. Atrophy of type II fibres as part of diminished fat free mass has been suggested as the underlying cause of the correlation between body weight and maximal oxygen consumption.[2]

The relation between the distance covered in 12 minutes' walking and nutritional state is more difficult to explain as fast fibres will probably be recruited less during submaximal exercise than during maximal exercise. Three additional mechanisms are postulated. Firstly, atrophy of fast twitch fibres with a reduction of maximum force output predisposes the diaphragm to fatigue as this is related to the level of force generated during breathing expressed as a percentage of the maximum force achievable. A second mechanism is suggested by Lopes *et al*, who found increased muscle fatiguability and slowing of relaxation of the adductor pollicis muscle in undernourished patients with gastrointestinal disease.[33] As this increase occurred without change in local blood flow the slower muscle relaxation rate and increase in muscle fatiguability were explained by a decrease in local energy stores of the limb muscles. Efthimiou *et al* showed similar changes as well as reduced strength in the sternomastoid muscle in underweight patients with chronic obstructive pulmonary disease. Donahoe *et al* found an increase in oxygen consumption of the ventilatory muscles for a given level of ventilation in underweight patients with chronic obstructive pulmonary disease.[34] The increased oxygen consumption of the ventilatory pump could therefore be a third exercise limiting factor in these patients by decreasing the proportion of total available oxygen for the exercising limb muscles.

We conclude that muscle mass is an important determinant of exercise performance in patients with severe chronic obstructive pulmonary disease, independent of the degree of airflow obstruction.

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