Anaerobic Performance—Assessed by the Wingate Test—in Patients With Cystic Fibrosis

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Cystic fibrosis (CF) patients were studied to investigate the muscles' ability to produce and sustain high-intensity short-term exercise in this population. The patients, 17 males and 23 females, ranged from 10 to 39 years of age. Each patient performed a pulmonary function test followed by a Wingate Anaerobic Test (WAnT). Based on a pulmonary function scoring system, patients were classified as having severe, moderate, or mild lung dysfunction, or normal lung function. Percent ideal body weight was used to categorize the patients as nourished or malnourished. Two indices of anaerobic performance (peak power and mean power) were determined from the WAnT and normalized by actual weight or by ideal weight. Patients in the severe and moderate groups had lower peak power (PP) and lower mean power (MP) than those in the mild and normal groups. Similarly, malnourished patients showed a lower PP and MP than did nourished patients. These results were similar regardless of whether PP or MP were normalized by weight or ideal weight. It is concluded that the anaerobic performance (muscle power and endurance) of CF patients, as assessed by the WAnT, was related to the degree of severity of the overall disease process.

Most children and young adults with cystic fibrosis (CF) have an impaired exercise tolerance (11, 12). In particular, CF patients with normal or mild lung dysfunction have a normal exercise tolerance, while for those with moderate or severe lung dysfunction the exercise limitation becomes more prominent (7, 9). Although this exercise limitation is mainly pulmonary in nature, other factors such as nutritional status may contribute to this limitation (8, 19).

Nutritional deficiency in CF ranges from mildly depleted fat stores to severe protein malnutrition (21). Deficiencies are most likely to occur at times of rapid growth, during pulmonary exacerbations, and with increased severity of lung disease (21). Malnutrition leads to a loss of body fat and then to muscle wasting. Malnutrition can also have adverse metabolic and structural effects on skeletal muscles (18). These adverse effects may affect the anaerobic power and endurance of the contracting muscles, and consequently exercise performance.

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In various pediatric disorders (e.g., muscular dystrophy, cerebral palsy), peak muscle power and local muscle endurance are deficient (2, 3, 22). It can be speculated that in a multisystem disease such as CF, not only will the peak aerobic power limit the child’s ability to exercise, but also the peak anaerobic power of the contracting muscles may contribute to this limitation, especially in those with advanced disease (5). To our knowledge, there is no information on the ability of the leg muscles to perform high-intensity exercise in a CF population that has a wide range of lung function and nutritional status. The muscle’s limited ability to perform supramaximal exercise of short duration may be a contributing factor to the subnormal exercise performance observed in these patients (9, 12).

The ability of a muscle group to perform high-intensity short-term exercise (i.e., muscle power or muscle endurance) can be assessed by the Wingate Anaerobic Test (WAnT) (2, 4). The WAnT is designed to assess the ability of a muscle group to perform short supramaximal tasks (two to three times the maximal aerobic power). In such tasks, the limiting factor is not the oxygen transport system but rather the muscles’ ability to anaerobically convert chemical energy to mechanical energy (2, 4, 15).

The energy to perform most types of exercise comes from a combination of anaerobic and aerobic sources of energy production. The contribution of anaerobic adenosine triphosphate (ATP) production is greater in short-term high-intensity activities, while aerobic metabolism predominates in activities of longer duration. An incremental exercise test of 10 minutes duration may require approximately 85% aerobic and 15% anaerobic production of ATP. On the other hand, during a 30-second WAnT only ~19% of the total work performed comes from aerobic sources of energy production.

It is well known that the exercise limitation in CF is mainly pulmonary, and that the extent of this limitation is correlated with the degree of lung dysfunction (12). A limited capacity to oxygenate the blood perfusing the lungs will affect the oxygen transport system, and thereby the effectiveness of the aerobic pathway of energy production. However, since the performance during a WAnT depends mainly on the ability to convert anaerobically chemical energy into mechanical energy, the performance of CF patients during a WAnT should not be directly related to the severity of airway obstruction. If the anaerobic power and endurance of the contracting muscles do indeed limit the ability to exercise in CF, then we would expect lower anaerobic performance in patients whose advanced disease has resulted in malnutrition and muscle deterioration.

The purpose of this study was to investigate the muscles’ ability to produce and sustain high-intensity short-term exercise in CF patients with a wide range of lung function and nutritional status. Our specific aim was to determine whether anaerobic power and endurance of the contracting muscles are contributing factors that limit the CF patient’s ability to perform exercise.

Subjects and Methods

The study population consisted of 40 patients (17 males, 23 females) with documented CF who were followed on a regular basis at the Cleveland Cystic Fibrosis Center. The diagnosis was confirmed by an elevated pilocarpine iontophoretic sweat chloride (>60 mEq/L). This population formed a heterogeneous group in terms of age and disease severity. The patients ranged from 10 to 39 years of
age (22 ± 7 yrs). Fourteen patients were younger than 18 years, 22 were between
18 and 30, and 4 were older than 30. All patients were receiving standard
CF therapy including aerosol therapy, chest physiotherapy, pancreatic enzyme
replacement, and antibiotic therapy as indicated. The study protocol was approved
by the Institutional Review Board and informed consent was obtained from the
patient or parent. All patients performed pulmonary function tests (PFT) followed
by a Wingate Anaerobic Test (WAnT).

**Pulmonary Function Tests**

The volume of thoracic gas (TGV) at functional residual capacity, the airway
resistance (Raw), and airway conductance (Gaw) were determined using a total
body plethysmograph (Medical Graphics, Model 1085). Specific Gaw (SGaw)
was calculated from Raw and the simultaneously measured TGV. Vital capacity
(VC) and its subdivisions, inspiratory capacity and expiratory reserve volume,
were measured using a flow-sensing spirometer (Medical Graphics, Model 1070).
Flow during a forced vital capacity was also measured using the flow-sensing
spirometer. Computed parameters included forced expired volume in 1 second
(FEV₁), mean flow between 25 and 75% of FVC (FEF₂₅₋₇₅%), peak expiratory
flow, total lung capacity, and residual volume (RV). All pulmonary function data
were collected according to American Thoracic Society standards and were
expressed as percent of predicted values, based on published data of Knudson
et al. (16) and Weng and Levison (23). Estimates of arterial oxygen saturation
(SaO₂%) were obtained at rest using a finger pulse oximeter (Nellcor, N-100).

The severity of lung dysfunction in our patients was expressed quantitatively
by a pulmonary function score (PFS). This score is derived from six lung function
parameters (VC, FEV₁, FEF₂₅₋₇₅%, RV, SGaw, and SaO₂%) as described by Cropp
et al. (9). Based on PFS, our patients were grouped as having severe (SE), PFS>
12; moderate (MO), 8≤PFS≤12; or mild (MI) lung dysfunction, 3≤PFS≤7; or
normal (NL) lung function, PFS<3.

**Nutritional Status**

The nutritional status was assessed using the index recommended by the National
Cystic Fibrosis Foundation (21). Body weight and height were measured, and
ideal body weight for height, age, and sex was calculated for each patient using
the standards of Hamill et al. (13). An index of nutritional status, that is, percent
ideal body weight (%IBW), was derived by dividing the patient’s actual weight
(WGT) by his or her ideal body weight (IBW) and expressed as a percentage.
The normal range for this index is 90–110% (20, 21). Therefore, based on
their nutritional status as indicated by %IBW, our patients were categorized, as
nourished (N), %IBW≥90%, or malnourished (MN), %IBW<90%.

**Wingate Anaerobic Test**

The 30-second WAnT was administered as described by Bar-Or (2). Patients
performed this leg exercise at a predetermined workload on an electrically braked
cycle ergometer (Siemens-Elema, 380B) set in the constant torque mode. The
control unit of the cycle ergometer was connected to a personal computer
(IBM-XT) equipped with a data acquisition and control module. The computer
system was programmed to set the desired workload on the ergometer and to
monitor the subject's pedaling speed (rpm) and power output (watts) throughout the test. From the instantaneous power output signal, mean power output (watts) was computed and all three signals were displayed on-line versus time every 250 msec.

The test was preceded by a 3- to 5-min warm-up period at 20 watts followed by a set of three trials of all-out sprints lasting 3–5 seconds (10). These trials were used for learning the test procedure and for determining the highest workload the subject was able to sustain for 30 seconds (10). The workloads ranged between 100 and 230 watts for patients in the SE and MO groups, and between 200 and 400 watts for those in the MI and NL groups. Once the test workload was determined, the patient rested for 5 minutes and then performed the test. Patients were given verbal encouragement throughout the 30-second period.

Two indices of anaerobic performance were obtained from the WAnT: peak power (PP), the highest mechanical power obtained during the testing period, and mean power (MP), the power averaged over 30 seconds. These indices were normalized in two similar forms: by body weight (PP/WGT, MP/WGT) and by ideal body weight (PP/IBW, MP/IBW). Next, we compared peak and mean power per body weight (i.e., PP/WGT and MP/WGT) to normal values reported in the literature (2, 6, 14) and expressed PP and MP as percent predicted.

Data Analysis

Data are reported as mean ±SD unless otherwise specified. The difference between group means for pulmonary function score (PFS), actual weight, and percent ideal body weight was tested for statistical significance using analysis of variance. The effects of pulmonary function and nutritional status on the two normalized indices of anaerobic performance (i.e., peak and mean power per body weight) were tested separately via one-way analysis of variance. Statistical significance was implied by a p value of 0.05 or less.

Results

Our patient population formed a heterogeneous group in terms of disease severity, as evidenced by the wide variation in lung dysfunction (PFS) and nutritional status (%IBW) (Table 1). Even though our population consisted of children and young adults, there was no statistically significant difference in mean age or height between any of the groups.

The degree of lung dysfunction (PFS) was significantly different between any two of the patient groups (P<0.0001). The main advantage of using this aggregate index of overall lung function status is that it is completely quantitative. In our study, PFS proved to be an excellent indicator of the degree of lung dysfunction that categorized the patients appropriately (Table 1).

The nutritional status was similar for patients in the severe and moderate groups, and those in the mild and normal groups, as indicated by the %IBW of these groups. However, %IBW for those in either the severe or the moderate group differed from %IBW in either the mild or the normal group (P<0.005) (Table 1). When we used the classification of nourished or malnourished, all but two of the patients in the severe and moderate groups were malnourished, and all but one patient in the mild and normal groups were nourished. Thus the
### Table 1

**Lung Function and Nutritional Status**

<table>
<thead>
<tr>
<th>Severity</th>
<th>PFS weight (kg)</th>
<th>Actual weight (kg)</th>
<th>% Ideal body weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Severe</td>
<td>14.6</td>
<td>1.2</td>
<td>43.3</td>
</tr>
<tr>
<td>Moderate</td>
<td>10.0</td>
<td>1.3</td>
<td>46.7</td>
</tr>
<tr>
<td>Mild</td>
<td>5.4</td>
<td>1.6</td>
<td>58.5</td>
</tr>
<tr>
<td>Normal</td>
<td>1.3</td>
<td>0.9</td>
<td>59.6</td>
</tr>
</tbody>
</table>

*Note.* Pulmonary function score (PFS) was different between any two groups of patients, \( P < 0.0001 \). The severe and moderate groups were different for weight and percent ideal body weight than either the mild or normal groups, \( P < 0.005 \).

### Table 2

**Anaerobic Performance Grouped by Degree of Lung Dysfunction**

<table>
<thead>
<tr>
<th>Severity</th>
<th>PP/WGT (Watts/kg)</th>
<th>PP/IBW (Watts/kg)</th>
<th>MP/WGT (Watts/kg)</th>
<th>MP/IBW (Watts/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Severe</td>
<td>5.57</td>
<td>1.21</td>
<td>4.41</td>
<td>1.04</td>
</tr>
<tr>
<td>Moderate</td>
<td>5.55</td>
<td>1.12</td>
<td>4.59</td>
<td>1.23</td>
</tr>
<tr>
<td>Mild</td>
<td>6.67</td>
<td>2.34</td>
<td>6.85</td>
<td>1.87</td>
</tr>
<tr>
<td>Normal</td>
<td>8.08</td>
<td>1.75</td>
<td>7.76</td>
<td>1.58</td>
</tr>
</tbody>
</table>

PP/WGT = Peak power per actual body weight; PP/IBW = Peak power per ideal body weight; MP/WGT = Mean power per actual body weight; MP/IBW = Mean power per ideal body weight.

Limited data in the severe/nourished, moderate/nourished, and normal/malnourished subgroups made it impossible to separate the effects of nutritional status and lung dysfunction on the anaerobic exercise performance in this population.

Peak power and mean power per body weight were lower (\( P < 0.005 \)) for patients in the severe and moderate groups than those in the normal PFS group (Table 2). However, when normalized by ideal body weight, peak power and mean power for those in the severe and moderate groups were even lower (\( P < 0.001 \)) than for those in either the mild or the normal PFS groups (Figure 1). Both peak power and mean power per ideal body weight were lower (\( P < 0.0005 \)) in the malnourished group than in the nourished group (Figure 2).

Finally, the anaerobic performance of our patients was evaluated by comparing it to normal values reported in the literature or from our laboratory (2, 6, 14). Peak and mean power were expressed as percent predicted of normal values for age and sex, for each degree of lung dysfunction. Patients with normal lung function had
Figure 1 — Anaerobic performance of CF patients (mean ±SE) expressed per actual body weight (blank) and per ideal body weight (diagonal): (A) peak power and (B) mean power. Asterisks denote significant differences (P<0.01) from the group of CF patients with normal lung function (NL).

a normal anaerobic performance during the Wingate Test, as evidenced by the peak power (101 ±15%) and mean power (97 ±18%) achieved (Figure 3). Both peak and mean power were lower (P<.005) in the severe group (PP: 70 ±10%; MP: 69 ±11%) and moderate group (PP: 73 ±15%; MP: 75 ±13%) than in the normal group. The anaerobic performance of those in the mild group, on the other hand, was lower than the predicted normal but showed large variation among individuals (PP: 84 ±28%; MP: 82 ±26%), and therefore was not statistically different.

Discussion

The 30-second Wingate test has been used extensively to assess anaerobic performance (21). Its validity and reliability has been tested in healthy children,
Malnourished and nourished CF patients. Data are mean ±SE. Asterisks denote significant differences (*P<0.001) between nourished and malnourished CF patients.

Figure 2 — Peak power (PP) and mean power (MP) per ideal body weight in nourished and malnourished CF patients. Data are mean ±SE. Asterisks denote significant differences (*P<0.001) between nourished and malnourished CF patients.

adolescents, and young adults (6, 10, 14) and in 6- to 20-year-old patients with neuromuscular disease (22). The two WAnT indices of performance—peak power and mean power—are assumed to reflect, respectively, the ability of the exercising muscles to produce (muscle power) and sustain (muscle endurance) high mechanical power in a short time (4). In CF, with advanced airway obstruction and muscle wasting, a decrease in local muscle performance may accompany a reduction in maximal aerobic power. Furthermore, changes with time in muscle power and endurance may be related to the progression of the disease (21).

Patients with CF, especially those with advanced disease, often exhibit malnutrition as well as severe airway obstruction. Coates et al. (8) and Marcotte et al. (18) demonstrated that aerobic exercise intolerance correlates with the degree of airway obstruction and nutritional status. A recent study by Lands et al. (17) suggests that mild malnutrition in CF affects the size of the muscle mass and consequently skeletal muscle function, and that in addition to lung disease as a limiting factor, leg muscle function is a sensitive determinant of maximal exercise performance.

Our results suggest that the anaerobic performance in CF patients, as assessed by the WAnT, is dependent on the degree of severity of their disease. In this study, both peak power and mean power were reduced in patients with moderate and severe lung dysfunction when compared to patients with normal lung function. Similar reductions were also observed in both peak power and mean power when comparing nourished to malnourished patients. In both cases, statistically significant differences were obtained whether PP or MP were normalized by actual weight or by ideal weight (Figure 1). When expressed per ideal body weight, the differences observed for peak power and mean power between either the moderate or severe group and the normal group were even larger.

To eliminate the potential confounding factor of difference in body size being associated with age between the groups, peak and mean power were expressed as percent predicted of normal (2, 6, 14). Patients with normal lung
Anaerobic Performance

Mean Power

Figure 3 — Peak power and mean power (mean ±SE) expressed as percent predicted (% pred) from normal values, in a group of CF patients with various degrees of lung dysfunction. Asterisks denote significant differences (P<0.01) from the group of CF patients with normal lung function (NL).

function maintained normal peak and mean power as compared to the moderate and severe groups (Figure 3).

These results suggest that either the degree of lung dysfunction, the nutritional status, or both together may limit the anaerobic performance of patients with cystic fibrosis. However, since performance during the WAnT is mostly dependent on the anaerobic characteristics of the exercising muscles and not on the oxygen transport system, differences in the degree of lung dysfunction should not significantly affect the outcome of this anaerobic test. Therefore, nutritional status may be the main factor that limited the anaerobic exercise performance in our group of patients. More specifically, this limitation may be due to muscle deterioration resulting from the degree of malnutrition we observed in patients in the moderate and severe groups.

Marcotte et al. (18) evaluated the effect of nutritional status on the physiological responses to exercise in CF by studying a homogeneous population of patients in terms of lung function but with varying degrees of nutritional compromise. They concluded that exercise performance in CF, in addition to being related to the degree of respiratory impairment, is also independently influenced by nutritional status. In our study it was not possible to test the independence of these contributing factors to the limitation in anaerobic performance in these patients, since all but two patients in the MO and SE groups were malnourished and all but one patient in the MI and NO groups were nourished.

Although CF is a multisystem disease, deterioration in lung function has commonly been used as the major indicator of the disease progression and considered as the main cause of exercise limitation. However, other factors such as nutritional status may contribute to the exercise limitation (19). In particular, malnutrition can affect the metabolic and structural characteristics of skeletal muscle (8, 18). Arora and Rochester (1) demonstrated that malnutrition induces reductions in both respiratory muscle strength and maximal voluntary ventilation,
and thus may impair respiratory muscle capacity. Since CF patients require a higher level of ventilation at rest and during exercise, decreases in respiratory muscle capacity may well limit their exercise performance (8). In addition, malnutrition may lead to loss of leg muscle mass, and consequently to diminished leg muscle power and endurance. The present study demonstrates the deleterious effects of malnutrition on muscle power and endurance in our CF population with more advanced lung dysfunction.

Our observations complement Lands et al.’s (17) and Marcotte et al.’s (18) findings that the combined effects of airway obstruction, nutritional status, and skeletal muscle function play a measurable role in limiting maximal exercise performance in patients with CF. Our results further support the concept that the degree of pulmonary dysfunction is the primary limiting factor to exercise in patients with CF, and that malnutrition, with its adverse effects on local muscle power and endurance, also plays a significant role in this limitation. Further studies using a larger sample size and additional indicators of nutritional status are warranted.

References


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