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PULMONARY FUNCTION AND SYMPTOM-LIMITED EXERCISE STRESS TESTING IN SUBJECTS WITH LATE SEQUELAE OF POLIOMYELITIS

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ABSTRACT. Sixty-eight subjects, consecutively admitted to our rehabilitation hospital with a presumptive postpolio syndrome, were examined by pulmonary function and symptom-limited exercise stress testing. The purpose of this investigation was to study how many of these subjects could be classified as suffering from cardiorespiratory deconditioning. The subjects had moderately reduced lung function of restrictive type, and none of the subjects had forced expiratory volume for one second (FEV_1) below 30% of predicted value, indicating that hypoventilation would probably not occur. A pronounced reduction in maximal oxygen uptake (max $\dot{V}O_2$) was seen, especially in women. The maximal heart rate (max HR) values were above 70% of predicted values in all but one subject, indicating that the subjects might benefit from endurance training. Fifteen subjects had a suspected pulmonary limitation due to the exercise, with the ratio ventilation/maximal voluntary ventilation ($\dot{V}$/MVV) above 70%. However, max HR in these subjects did not differ from that in the subjects with the ratio $\dot{V}$/MVV below 70%. Thirteen other subjects had a ratio $\dot{V}$/MVV $<70\%$ but did not achieve respiratory quotient (R) > 1.0 and/or capillary lactate concentration >4 mmol/l during exercise, indicating that muscular factors limited the exercise. These results indicate that cardiorespiratory deconditioning was considerable in most of our subjects with postpolio syndrome.

Key words: postpolio syndrome, poliomyelitis, lung function, exercise testing.

The purpose of this study was to determine the pulmonary function and the responses during symptom-limited exercise stress testing in patients with presumptive postpolio syndrome, and to investigate whether cardiorespiratory deconditioning may contribute to the most common new health problems experienced by these subjects.

The negative consequences of inactivity of the cardiorespiratory system are well known (23), and these effects can be accentuated in subjects with late sequelae of poliomyelitis. General fatigue, weakness and reduced endurance, with associated functional deterioration, may thus also be caused by cardiorespiratory deconditioning (1).

Cardiorespiratory function associated with postpoliomyelitis sequelae have been more scarcely described than the neurological and musculoskeletal problems (18, 21). Hitherto, there are relatively few reports on exercise testing in these subjects (8). We have therefore examined 68 subjects, consecutively admitted to our rehabilitation hospital because of presumptive postpolio syndrome, using pulmonary function and exercise stress testing. Our aim was to study especially how many of these subjects could be classified as having cardiorespiratory deconditioning, and how many of them were unable to perform cardial stress maximally, due to pulmonary, neurological or musculoskeletal problems.

MATERIAL AND METHODS

Sixty-eight patients with late sequelae of poliomyelitis consecutively admitted to the Sunnaas Rehabilitation Hospital over a period of 3 years were included in the study. The patients were 45 women and 23 men, aged 28–74 years (mean 53 years). Characteristics of the subjects are presented in Table I. An additional 6 patients with late sequelae of poliomyelitis admitted to the hospital during the same time period had too severe paresis to take part in the test procedures, and were thus excluded from the material.

The patients were admitted to the hospital because of presumptive postpolio syndrome according to their history of original polio, functional improvement and late deterioration (15, 17). No further distinction was made concerning the diagnosis of postpolio syndrome.

Spirometry was performed by dry spirometry (Vitalograph Compact, Vitalograph Ltd, Birmingham, England). The

Table I. *Characteristics of 68 subjects with late sequelae of poliomyelitis*

Values are given in mean ± 1 SD.

BMI = body mass index (reference values 19–25).

	Women	Men
n	45	23
Age (years)	53 ± 11	52 ± 10
Height (cm)	162 ± 6	172 ± 8
Weight (kg)	63 ± 15	73 ± 13
BMI (weight/height^2)	24 ± 6	25 ± 3
Age at primary infection (years)	12 ± 5	9 ± 4
Stable phase of the disease (years)	36 ± 8	35 ± 7
Time since new symptoms (years)	5 ± 4	9 ± 5

measured forced vital capacity (FVC), forced expiratory volume for one second (FEV_1), and maximal voluntary ventilation (MVV) were compared with predicted values for sex, height and age in healthy persons (14).

Exercise testing was performed either with an arm ($n = 31$) or leg ($n = 37$) bicycle ergometer (Jaeger, Würzburg, Germany). Nine of the subjects who bicycled with arm ergometry suffered from paresis in one or both upper extremities, and 31 of the subjects who were tested with leg ergometry suffered from paresis in one or both lower extremities. We have, however, no objective measurements of the muscle strength in the extremities used during the bicycle test, and the results of the exercise test were not evaluated in relation to the individual's paresis.

The subjects pedalled at intervals of 3 min with a 2-min pause between the intervals. Most subjects who performed arm ergometry started with a workload of 10 W, with increases of 20 W for every interval, while subjects who performed leg ergometry usually started with a workload of 25 W, which increased by 25 or 50 W every interval until exhaustion. The subjects rated their subjective perceived exertion at the end of the exercise test according to the Borg scale (5).

Oxygen uptake ($\dot{V}O_2$), ventilation ($\dot{V}$) and respiratory quotient (R) were measured every 30 s during exercise (Jaeger EOS Sprint Exercise System, Würzberg, Germany). Peak $\dot{V}O_2$ was labelled maximal $\dot{V}O_2$ (max $\dot{V}O_2$), even if some subjects did not reach the criteria for max $\dot{V}O_2$ (26). The capillary concentration of lactate was measured (Model 23 L Lactate Analyser, Yellow Springs Instrument, USA) 3 min after the end of the exercise test in 27 subjects. Max $\dot{V}O_2$ was compared with predicted average values for age and sex in healthy persons (26). Predicted max $\dot{V}O_2$ with arm ergometry was presumed to be 70% of predicted max $\dot{V}O_2$ with leg ergometry (26).

Heart rate (HR) was followed by continuous electrocardiogram recording (Cardiac Monitor 573, Kone, USA). Registered maximal HR (max HR) was compared with predicted maximal HR (pred max HR) for age, using the formula: 220 beats/min minus the subject's age = pred max HR (26). Subjects with max HR above 90% of the predicted value were presumably "normals" regarding stress on the cardiovascular system, and subjects with max HR above 70% of the predicted value were presumed to be able to achieve maximal stroke volume and therefore probably capable of obtaining good benefit from endurance training (26).

The results are given in mean ± 1 SD and range. Comparisons between groups were obtained using Student's *t*-test. The criterion for statistical significance was $p < 0.05$.

RESULTS

Pulmonary function values are shown in Table II, indicating that the subjects had on average a moderately reduced lung function of restrictive type. Six subjects, however, had FEV_1 below 1.5 l. Two of these had FEV_1 lower than 1.0 l, and these 2 subjects also had FVC below 1.5 l. None of the subjects had FVC or FEV_1 below 30% of predicted values (Table II). Five subjects had a ratio FEV_1/FVC of less than 65% (range 52–64%), indicating marked pulmonary obstruction. The ratio MVV/FEV_1 was on average 35 ± 8 in women and 41 ± 8 in men.

Table III shows the cardiopulmonary values at peak exercise in subjects who exercised with arm ($n = 31$) and leg ($n = 37$) ergometry, respectively. Max $\dot{V}O_2$ was on average severely reduced, especially in women. Given as percentage of predicted values, max $\dot{V}O_2$ was similar in subjects who performed arm ergometry compared with max $\dot{V}O_2$ in subjects who performed leg ergometry, both for women and men. Four subjects had max $\dot{V}O_2$ above 100% of predicted values, and an additional 2 subjects had above 90% of predicted values in max $\dot{V}O_2$. Thirty-two subjects had max $\dot{V}O_2$ below 60% of predicted values, and 16 of these subjects had less than 50% in max $\dot{V}O_2$.

Table II. *Pulmonary function values for 68 subjects with late sequelae of poliomyelitis*

Values are given in mean ± 1 SD and range (given in parentheses).

No statistically significant differences between lung functions in women and men. *FVC* = forced vital capacity, FEV_1 = forced expiratory volume in one second, *MVV* = maximal voluntary ventilation.

Lung functions	Women ($n = 45$)	Men ($n = 23$)
FVC (% pred)	97 ± 23 (38–146	87 ± 21 (36–119)
FEV_1 (% pred)	87 ± 20 (34–132)	81 ± 20 (36–107)
FEV_1/FVC (%)	75 ± 7 (59–100)	73 ± 8 (52–86)
MVV (% pred)	85 ± 25 (34–160)	86 ± 26 (29–133)

Table III. *Values at maximal exercise in 68 subjects with late sequelae of poliomyelitis who performed arm or leg ergometry*

Values are given in mean ± 1 SD and range (in parentheses).

$\dot{V}O_2$ = oxygen uptake, *HR* = heart rate, $\dot{V}$ = ventilation, *MVV* = maximal voluntary ventilation, *R* = respiratory quotient.

	Women		Men	
Variable	Arm (n = 21)	Leg (n = 24)	Arm (n = 10)	Leg (n = 13)
$\dot{V}O_2$ (ml/kg/min)	14 ± 5 (6–25)	21 ± 6* (14–37)	18 ± 6 (12–30)	27 ± 6 (16–37)
$\dot{V}O_2$ (% pred)	59 ± 20* (28–111)	59 ± 15* (40–103)	76 ± 18 (54–106)	71 ± 15 (42–96)
HR (% pred)	91 ± 7 (74–103)	92 ± 10 (72–107)	96 ± 10 (81–109)	99 ± 11 (68–112)
$\dot{V}$/MVV	50 ± 17* (23–91)	64 ± 18 (37–96)	61 ± 14 (39–86)	59 ± 16 (43–95)
R	1.13 ± 0.14 (0.93–1.41)	1.12 ± 0.14 (0.87–1.41)	1.18 ± 0.15 (0.94–1.41)	1.14 ± 0.10 (0.96–1.32)
Lactate (mmol/l)	4.3 ± 1.7* (2.0–7.4)	6.1 ± 2.1 (2.4–8.5)	6.3 ± 0.3 (6.1–6.5)	7.3 ± 1.9 (4.2–9.4)
Borg's scale	17 ± 2 (15–20)	19 ± 2 (13–20)	18 ± 2 (15–20)	19 ± 1 (17–20)

* = significant difference $p < 0.05$ between results for women and men.

Forty-three subjects achieved max HR above 90% of predicted value during exercise. Max $\dot{V}O_2$ in these subjects were 70 ± 17% of predicted values (range 40–106%). Twenty-one subjects achieved max HR between 70% and 90% of predicted value during exercise, and max $\dot{V}O_2$ was on average 55 ± 20% (range 28–111%) in this group. One subject, a 46-year-old man, had max HR below 70% of predicted values during exercise. He achieved a max HR of 119 (68% of predicted value), and a max $\dot{V}O_2$ of 42% of predicted value.

The ratio $\dot{V}$/MVV was above 70% in 15 subjects, above 80% in 8 of these subjects, and above 90% in 3 of them. Max HR in these groups were, respectively, 94 ± 10%, 90 ± 7% and 92 ± 1% of predicted values. In comparison, max HR was 94 ± 10% of predicted values in the subjects who had a ratio $\dot{V}$/MVV below 70%.

Fifteen of the subjects had peak R < 1.0 and/or peak capillary lactate concentration below 4.0 mmol/l. Max HR in these subjects was 86 ± 6% of predicted values, significantly lower than max HR (95 ± 9% of predicted values) in those who achieved R ≥ 1.0 and/or capillary lactate concentration ≥4.0 mmol/l during exercise. Only 2 of the subjects with R < 1.0 and/or capillary lactate concentration <4.0 mmol/l during exercise had a ratio $\dot{V}$/MVV above 70% during maximal exercise.

DISCUSSION

The principal finding of this investigation was severely reduced cardiorespiratory fitness in the subjects with presumptive postpolio syndrome, more pronounced in women than in men (Table III). However, only one subject had max HR below 70% of predicted value, indicating that most of these patients should be able to achieve maximal stroke volume during exercise, and should thus have the possibility of reconditioning through both central and peripheral adaptation towards an increased aerobic capacity (26).

Even subjects with "normal" max HR (above 90% of predicted value) had reduced max $\dot{V}O_2$, indicating that cardiorespiratory deconditioning may be an important reason for the reduced endurance capacity in these subjects.

According to one study (10), clinical symptoms of hypoventilation can appear at a vital capacity below 1.5 l or 30% of predicted value. Even if some of our subjects had an FVC and FEV_1 of less than 1.5 l, none of those values were below 30% of predicted values (Table III), indicating that hypoventilation would probably not occur in these subjects. However, blood gas values were not measured during the exercise test.

The ratio MVV/FEV_1 indicated on average a reasonably good endurance of the respiratory muscles and mobility of the thorax. Fifteen subjects had $\dot{V}$ above 70% of their MVV during exercise, which could indicate a pulmonary limitation of exercise (26). However, max HR in these subjects was not significantly different from max HR in subjects who achieved less than 70% in the ratio $\dot{V}$/MVV during exercise. This finding indicates that pulmonary limitation during exercise was of minor importance in most of our subjects.

New impairment of breathing is a matter of great concern to many polio survivors. Halstead et al. (16) reported that as many as 42% of the postpolio subjects had "shortness of breath" as one of the new health problems. This symptom might be due to reduced cardiopulmonary fitness rather than to respiratory problems. In other studies the frequency of new respiratory problems is less (15, 24), which may be accounted for by the different ways of reporting respiratory problems and by the selection of different study groups. Patients with major respiratory problems are usually not admitted to our rehabilitation hospital, but rather to a department of pulmonary diseases. This is probably the main explanation of why most of our patients had reasonably good lung function.

A distinction must be made between weakened muscle fatigue and general fatigue associated with deconditioning. Fifteen of our subjects had $R < 1.0$ and/or capillary lactate concentration < 4.0 mmol/l, and only two of them had a ratio $\dot{V}$/MVV above 70%. Thus, muscle factors were probably a major limiting reason during the exercise test for this group. However, we cannot present data on measurements of muscle strength in the extremities used for the exercise test other than those showing a considerable number of subjects suffering from paresis in the working muscles. The Borg scale showed general fatigue during maximal exercise in most of the subjects (Table III).

The most common new health problems in subjects with a presumptive diagnosis of postpolio syndrome are general fatigue, new muscle weakness and muscle and joint pain (1, 4, 7, 15, 17). The same findings were confirmed among 42 of the subjects participating in this study (25). This study indicates that cardiorespiratory deconditioning may contribute to the new problems with fatigue, weakness and pain.

Saltin (23) demonstrated that young, healthy individuals can lose 25% of their cardiorespiratory fitness after 3 weeks of bed rest. Müller (20) demonstrated that young, healthy individuals can lose 20% of their strength after one week of immobilization.

There is some indirect evidence to suggest that disuse may play a role in postpolio subjects. Grimby et al. (12) reported a low citrate synthase concentration in the muscles of postpolio subjects, and believed it to be concomitant with a low level of activity in these individuals. A recent clinical report (2) showed that the concentration of HDL-cholesterol was significantly reduced in postpolio men. This probably reflected a reduced level of activity in these subjects because HDL-cholesterol concentration is known to increase with activity.

Cardiovascular endurance is a vital component of physical fitness. It is often ignored or difficult to achieve in individuals with a variety of neuromuscular or musculoskeletal diseases. Traditional muscle training or retraining and flexibility exercises constitute only part of the problems facing postpolio subjects. A comprehensive blend of flexibility, strength and endurance training should be developed to improve physical capacity. Use of exercise, however, as a treatment modality for postpolio sequelae has come under close scrutiny by the medical community because of fear of increased muscle weakness resulting from overuse (6, 22).

However, recent studies report that a reduction in prolonged strenuous activity combined with carefully prescribed progressive resistance exercises and cardiovascular conditioning has a positive effect on both muscle weakness and fatigue (9, 11, 21). Several short-term exercise studies have shown improved endurance capacity in postpolio subjects (13, 19). Intermittent activity taking rest breaks (interval exercise, pacing) is especially recommended, and has resulted in less local fatigue in postpolio subjects (1, 3).

Currently there is little knowledge regarding the effects of long-term aerobic exercise on the development or progression of the postpolio syndrome (19). However, there are also no well-controlled studies to support authors who argue against strenuous exercise programs for these subjects. Controlled studies are, therefore, needed to investigate the efficacy of postpolio syndrome exercise programs.

Aerobic or endurance training is said to be contraindicated for individuals who are operating with a high physiologic workload in order to perform their daily activities. In this case, a balance of activity and rest is prescribed to optimize work output and function (13). Few of our patients fall into this category. For the other subjects, in whom deconditioning could play a significant role, a modified program of aerobic exercise is not contraindicated. The type, intensity, frequency, duration and course of an aerobic exercise program should be prescribed on the basis of the assessment, activity-rest record and an exercise test as described above.

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