Endurance Training Effect on Individuals With Postpoliomyelitis

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ABSTRACT. Ernstoff B, Wetterqvist H, Kvist H, Grimby G. Endurance training effect on individuals with postpoliomyelitis. Arch Phys Med Rehabil 1996;77:843-8.

Objective: To determine the effects of an endurance training program on the exercise capacity and muscle structure and function in individuals with postpolio syndrome.

Design: Preexercise and postexercise testing was performed with muscle strength evaluations using isokinetic testing as well as hand-held Myometer. Muscle fatigue was determined by use of isokinetic testing, and endurance was determined by exercise testing. Enzymatic evaluation was performed with muscle biopsies taken at the same site; preexercise and postexercise muscle cross-sectional area was measured by computed tomography. Disability and psychosocial evaluation was performed by a Functional Status Questionnaire.

Setting: A university.

Subjects: Seventeen postpolio subjects ranging in age from 39 to 49 years volunteered for a 6-month combined endurance and strength training program. They had a history of acute poliomyelitis at least 25 years earlier and were able to walk with or without aid.

Intervention: Twelve of the subjects (mean age 42 years) completed the program, attending an average of 29 sessions, which were offered for 60 minutes twice a week.

Main Outcome Measures: Strength, endurance, enzymatic activity, and cross-sectional area were measured 3 months before the beginning of training, just before training, and at the completion of the exercise program.

Results: Knee extension was reduced to an average of 60% of control values and did not change with training. Strength measured with a hand-held Myometer increased significantly for elbow flexion, wrist extension, and hip abduction. Exercise test on a bicycle-ergometer showed significant reduction (6 beats/min) in heart rate at 70W and increase (12 beats/min) in maximal heart rate with training. The training program could be performed without major complications and resulted in an increase in muscle strength in some muscle groups and in work performance with respect to heart rate at submaximal work load.

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THE LAST POLIOMYELITIS epidemic occurred in the 1950s. Forty years later, individuals afflicted in that epidemic are at risk of sequelae to the disease. Sequelae include the onset of fatigue, muscle pain, joint pain, weakness, cold intolerance, increased sleep disturbances, and atrophy, which combined has been defined as the postpolio syndrome (PPS).[1] These new problems may lead to new deficits in activities of daily living (ADL), walking, climbing stairs, dressing,[1] and personal assistance, as well as loss of employment. Many etilogies have been postulated for these new problems, which include further loss of anterior horn cells, increased metabolic demand on the motor unit, and unstable neuromuscular connections.[1-3] In the last decade, the medical profession has become increasingly aware of these problems.[4,5]

Delorme[6] in 1948 described an exercise program that showed gains in overall function; he recommended a lifelong exercise program.[6] Presently, the exercises that have been described for postpolio sequelae have been of the nonfatiguing type. If the conditioning program is excessive, it may lead to further loss of function instead of improvement.[7-9]

These have been studies to determine whether strength or endurance training benefit postpolio sequelae individuals.[10-15] Strength training over a 6-week period has shown significantly improved strength in the trained leg. These gains were maintained over the next 5 to 12 months.[11] Nonfatiguing strengthening exercises have been reported to result in improvement over a long period of time.[12]

Endurance or aerobic exercise have also increased cardiopulmonary performance in postpolio sequelae subjects as evidenced by significant increase in aerobic capacity ($V0_2$) max. Jones et al[10] also reported no loss of isokinetic strength after completion of the aerobic training program.

Histologic evaluation has demonstrated a large variation in fiber typing from individual to individual with postpolio sequelae. The mean fiber area for all fiber types were about double the normal size.[2,16,17] It has been hypothesized that the increase in mean fiber area resulted from the samples greater stress placed on the remaining fibers causing the corresponding hypertrophy.[16,17]

Determination enzymatic activity from muscle biopsy samples have revealed a significant decrease in the concentration of the oxidative enzyme, citrate synthase (CS). Glycolytic enzyme activity, on the other hand, did not show any significant difference from control values.[17] It is possible that the decreased concentration of oxidative enzymes may be one of the causal factors of fatigue associated with activity reported by many postpolio individuals.

The effect of endurance training at the muscle level has not been evaluated, nor have its long-term effects been assessed.

The purpose of this study was to determine whether an endurance training program lasting approximately 6 months would increase exercise capacity and muscle structure and function without deleterious effect.

METHODS

Subjects

Seventeen subjects (5 men, 12 women) were included in this study. They were selected from a larger group of 32 subjects (10 men, 22 women). Of the 32 volunteers, 8 did not meet requirements to participate because of severe weakness, decreased mobility, inability to perform a full knee extension, or back pain; 7 did not wish to participate after having the procedures explained to them. Five of the remaining 17 volunteers did not complete the program (2 men and 3 women). Two subjects found the exercise program too difficult, one changed jobs, one became ill unrelated to this study, and one was lost to follow-up.

The ages of the remaining 12 (3 men, 9 women) ranged from 39 to 50 years (X [arithmetic mean] = 42yr). The age of onset of polio was between 1 and 11 years (X [arithmetic mean] = 4.7yr). All but 4 had symptoms of PPS according to Halstead's criteria.[1] The distribution of polio-affected muscles according to clinical history is presented in table 1. All subjects could walk and only one regularly used a cane. No lower extremity bracing was used.

Measurements of muscle strength, muscle fatigue, and graded exercise test (GXT) were taken 3 months before training, just before the training started, and at the end of the training period. Preexercise and postexercise muscle biopsies were also obtained.

table 1: Subjects Participating in the Training Study[1]

No.	Sex	Age (yr)	Time Since Onset of	PPS*	Grade of Present Polio Affection				
					RUE	LUE	RLE	LLE	Trunk

			Polio (yr)						
1.	F	45	41	Yes	3	3	4	4	1
2.	F	44	39	No	1	1	3	2	1
3.	F	48	37	No	1	1	1	3	1
4.	F	47	42	No	1	1	2	5	1
5.	F	48	39	Yes	1	2	1	3	2
6.	F	49	48	Yes	1	1	4	2	2
7.	M	44	42	Yes	1	1	4	1	1
8.	F	45	39	Yes	1	1	3	3	3
9.	M	45	39	Yes	1	1	4	4	1
10.	F	46	44	No	1	1	2	2	1
11.	M	50	48	Yes	1	4	1	4	1
12.	F	44	42	Yes	2	2	4	2	2

* As per criteria of Halstead and Rossi.[1]
¹ Grade 1 is no polio affection by history; grade 2 is verified polio affection but no subjective muscle weakness; grade 3 is polio affection and subjective weakness without progress; grade 4 is new or increased muscle weakness; grade 5 is severely atrophic muscles. RUE, right upper extremity; LUE, left upper extremity; RLE, right lower extremity; LLE, left lower extremity.

Muscle Strength Measurements

Strength evaluation was performed on a isokinetic/isometric Kin-Com dynamometer[a] for isometric strength at 60° of knee flexion and isokinetic concentric strength at an angular velocity of 60° and 120°/sec. Three maximal efforts were recorded at each setting. The highest peak torque of each test was used for analyses. Fatigue index evaluation of knee was performed on a isokinetic dynamometer[b] at 180°/sec for 50 repetitions.

Strength of both upper and lower extremities were measured with a hand-held Myometer.[c,18] Several major muscle groups of both upper and lower extremities were tested.

Graded Exercise Test (GXT)

All 12 individuals were tested using the same protocol, which consisted of continuous work loads of 30, 70, 100, and 130 watts on a bicycle ergonometer.[d] Each work-load stage lasted 4 minutes, Heart rate, respiratory rate, blood pressure (measured by cuff), and rating of perceived exertion and dyspnea[20] were monitored every 2 minutes.

Electrocardiogram (ECG) (Minograf 34*[d]*) monitoring was performed throughout the entire test.

Muscle Biopsy

Muscle biopsies were taken before and after training from the weakest leg.*[21]* This was performed from the mid portion of the vastus lateralis. The tissue was divided into two parts, one for histochemical analysis and the other for measurement of enzymatic activity. Preparation of the tissue, muscle fiber classification,*[15]* and histochemical evaluation*[17]* have been described in previous studies. Muscle fiber area was measured on a photo of the NADH stain and tracings were done using a digitizer table connected to a Mackintosh desk computer with a specially developed program. All measurements were done by the same technician.

The enzymatic activities for citrate synthase (CS), 3-hydroxy-acyl-CoA dehydrogenase (HAD), triasephosphate dehydrogenase (TPDH), lactate dehydrogenase (LDH), and myokinase (MK) were determined by fluorometer techniques described previously.*[17]* The protein content was determined and enzymatic activities were expressed per gram protein.

Muscle Cross-Sectional Area

Muscle areas were determined by computed tomography (CT) halfway between the upper crest of the patella and the anterior iliac spine, at the level of the performed muscle biopsies, before and after 6 months of training. The area of muscle was determined by circumscription of the muscle with the light pen of the CT scanner. The area of the CT numbers in the interval from 29 to 151 Hounsfield Units (HU), characteristic of muscle,*[22]* was then calculated. Separate assessment of the different thigh muscles could not be performed because of the pronounced changes of PPS.

Disability and Psychosocial Evaluation

Different functional aspects were evaluated using the Functional Status Questionnaire (FSQ) by Jette et al.*[23]* Summed scores were calculated for these categories according to the formula given by Jette*[23]* and used by Einarsson and Grimby.*[24]* The questionnaire was used in 8 subjects three months before the start of the training program and in all 12 subjects participating in the training immediately before and after the training period.

Training Sessions

The exercise sessions were performed twice a week for 22 weeks. A total of 40 sessions were given. The group training was interrupted during Christmas but home programs were given. A physiotherapist led each class and monitored the subjects. One of the authors was also present during each session. Music was used to pace and encourage the exercise. Each session lasted 60 minutes and consisted of 5 minutes of general warm-up followed by low-resistance, high-repetition exercise for all major muscle groups in both upper and lower extremities as well as the trunk. More time was spent on exercises specific for the quadriceps. After 1 month of training, 5 minutes of exercise on a bicycle was included at approximately 60% to 80% of maximal heart rate as determined by the

GXT. Heart rate was monitored regularly during training and the resistance on the bike was increased to maintain 60% to 80% of maximal heart rate. The amount of time on the bike remained at 5 minutes at each session. A 5-minute cool-down period followed at the end of each session. All subjects recorded the number of sessions attended in a log book. Physical complaints were also recorded.

Statistics

Wilcoxon's signed-rank test was used for statistical analysis and Spearman's rank correlation for analysis of correlation. Results were considered significant if $p < .05$.

Before participation, all subjects gave their informed consent to participate. The procedures were approved by the Ethical Committee of the Faculty of Medicine.

RESULTS

The average number of sessions attended by the participants was 29 (range from 16 to 37). The individual who attended only 16 sessions was enrolled in the program after the first 20 sessions. This individual was included to increase the sample size. This did not affect the statistical analyses.

The predominant complaints related to the exercise program were minor musculoskeletal discomfort of the lower extremities in 3 subjects. They were not specific to either limb. One other subject complained of progressive muscular fatigue in 26 of the 37 sessions attended.

The two pretests on muscle strength, fatigue, and graded exercise, which were performed 3 months apart, did not show any significant difference, except for 4% decrement in peak torque for 60° concentric knee-extension ($p < .05$). The peak torque values for knee-extension in the weakest leg were 61% ± 9%, 60% ± 8%, and 61% ± 7% of control values[17,25] for isometric (at 60° knee angle) and isokinetic strength at 60°/sec and 180°/sec, respectively. The corresponding values for the stronger leg were 78% ± 7%, 84% ± 8%, and 85% ± 7%; 8 of the 12 subjects also had a clinical history of polio in that leg, and 3 of them perceived muscle weakness.

Dynametric strength measurements before and after training showed no significant changes (fig 1). The reduction in peak torque during the fatigue test[19] in the weaker leg before training was 33% ± 5%, whereas after training, it was 23% ± 4% (fig 2). This change was statistically significant ($p < .05$). There was no significant ($p > .05$) change in the stronger leg with training; the corresponding values were 28% ± 3% and 29% ± 2% before and after training, respectively.

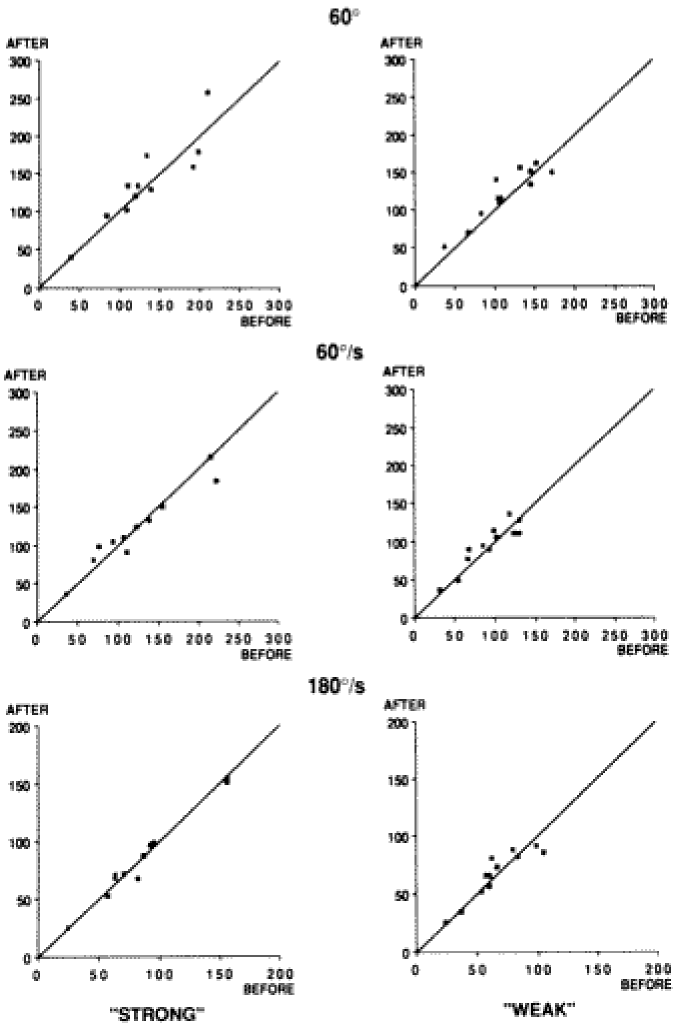

Fig 1. Peak torque (Nm) for isometric (60° knee angle) and isokinetic (60°/sec, 180°/sec) knee-extension for the "stronger" and "weaker" legs, respectively, before and after training. No value changed significantly ($p > .05$).

Strength measurements with the hand-held myometer showed significant increases ($p < .05$) in strength in right elbow extension, right wrist extension, and hip abduction bilaterally (table 2). There was no change noted in shoulder abduction, elbow flexion, neck flexion, knee flexion or extension, and foot dorsiflexion.

Table 2: Results of Myometer Measurements of Muscle Strength (N) Before and After Training in 12 Polio Subjects

	Before	After	Difference
Shoulder abduction			
Right	123 ± 9	139 ± 13	NS
Left	128 ± 6	138 ± 11	NS

Elbow flexion			
Right	206 ± 15	200 ± 11	NS
Left	190 ± 13	201 ± 9	NS
Elbow extension			
Right	125 ± 10	140 ± 12	$p < .05$
Left	124 ± 11	135 ± 12	NS
Wrist extension			
Right	150 ± 12	170 ± 14	$p < .05$
Left	144 ± 8	164 ± 11	NS
Neck flexion	85 ± 8	90 ± 9	NS
Hip abduction			
Right	125 ± 21	184 ± 25	$p < .01$
Left	127 ± 13	170 ± 19	$p < .01$
Knee flexion			
Right	149 ± 25	129 ± 23	NS
Left	156 ± 10	139 ± 11	NS
Knee extension			
Right	160 ± 15	157 ± 22	NS
Left	144 ± 40	132 ± 34	NS
Foot dorsiflexion			
Right	86 ± 43	119 ± 60	NS
Left	107 ± 18	131 ± 20	NS

Values given are mean ± standard error of the mean. Abbreviation: NS, not significant.

Significant correlations were found between the isometric measurements made with the isokinetic/isometric dynamometer and those with the hand-held myometer as measured before the start of the training period (right knee-flexion $n = 16$, $r = .71$; left knee flexion $n = 15$, $r = .74$; right knee extension $n = 10$, $r = .92$; left knee flexion $n = 8$, $r = .77$).

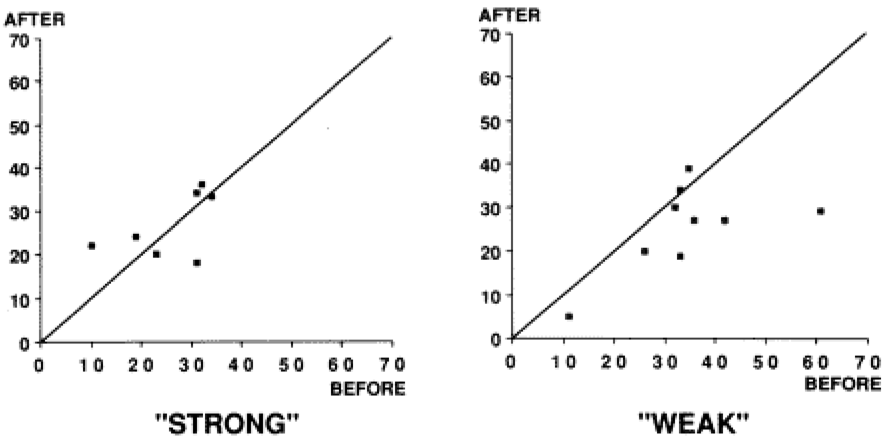

Fig 2. Percentage reduction in peak torque during the fatigue test with 50 consecutive isokinetic contractions at 180°/sec for the "stronger" and "weaker" legs, respectively, before and after training: no significant change (*p* > .051 in the "stronger" leg with training: significant (*p* < .05) change in the "weaker" leg comparing before and after training values.

Cross-sectional areas of the muscle fibers were large (fig 3). There were no significant changes (*p* > .05) in fiber area with training in any of the fiber types. However, it could be possible that there might be individual differences in the effect of training. Thus, changes in fiber size were compared with changes in strength. Significant correlations were found comparing change in mean fiber area and isokinetic strength (measured at 60°/sec) (*r* = .81, *p* < .01) (fig 4) and isometric strength (*r* = .76, *p* < .05). No significant correlations were found between change in mean fiber area and change in eccentric strength or with concentric strength (measured at 180°/sec).

A large variation was found between subjects in fiber proportions. In all subjects, there was a greater proportion of type IIA fibers than type IIB fibers. Atrophic fibers were noted to be of both major fiber types, with no significant increase between biopsy samples except in one subject. Group atrophy was found in only three subjects. All subjects had round atrophic fibers. Both internal nuclei and subjects splitting was occasionally noted.

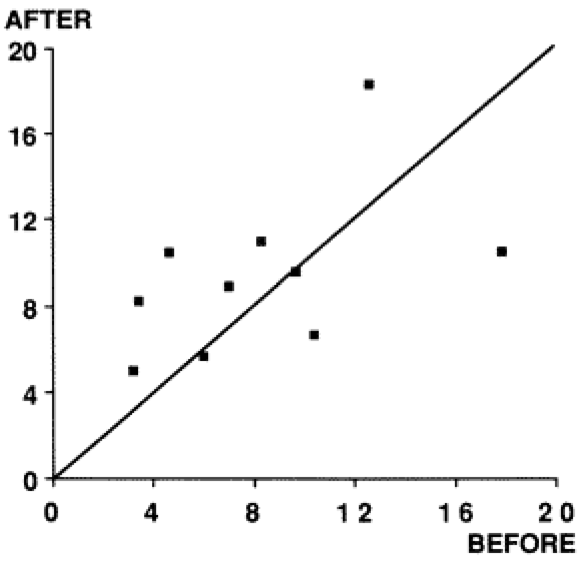

Fig 3. Cross-sectional mean fiber area (µcm² x 10³ in the vastus lateralis muscle of the "weaker" leg before and after training.

No significant (*p* > .05) change in thigh muscle area, in either the weaker or on the stronger side was found by CT examination. The average value for the total thigh muscle area was 98.8 ± 9.0cm² before and 92.5 ± 9.1cm² after training in the weaker leg. The corresponding values in the stronger leg were 119.0 ± 8.6cm² and 119.8 ± 8.9cm² before and after training. There were significant correlations (*n* = .62-0.70, *p* <.05) between concentric knee extension strength (measured at 60°/sec) and total thigh muscle cross-sectional area both before and after training.

The activity levels of CS, HAD, TPDH, LDH, and MK before training were 29.9 ± 3.0, 29.1 ± 2.8, 1439 ± 160, 868 ± 65 and 980 ± 11 .2µmol/min/g protein respectively and did not change significantly (*p* > .05) with training.

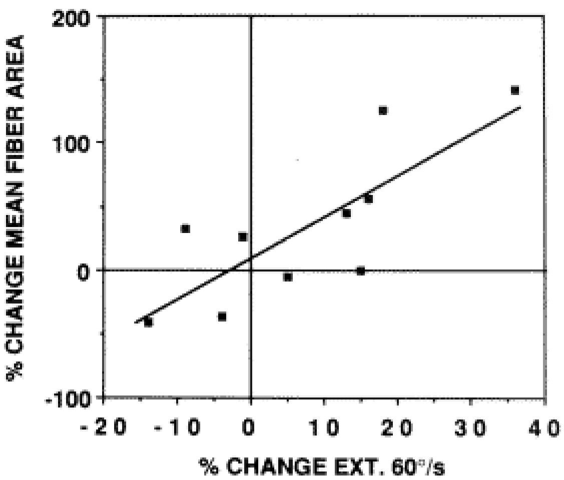

Fig 4. Relationship between percentage change with training in mean fiber area and in peak torque for knee-extension at 60°/sec (*r* = .80, p < .01).

A significant reduction was found in heart rate during bicycle ergometry following 70 watts with training program (*p* < .05) (fig 5). The average value was 133 ± 7 beats/min before and 127 ± 5 beats/min after training. The maximal heart rate achieved during bicycle ergometry was greater after training (*p* < .02) (fig 6). The mean value before the training program was 160 ± 5 beats/min before, whereas afterwards it was 172 ± 3 beats/min. In 8 subjects the maximal heart rate was below the age-corrected maximal heart rate (220 - age) before training. The rating of perceived exertion was lower after than before training in 9 of 12 subjects at corresponding workloads, but not significant for the group ($p > .05$).

The scores in the Functional Status Questionnaire (FSQ) did not change significantly ($p > .05$) with training (fig 7). There was no difference between the two pretests.

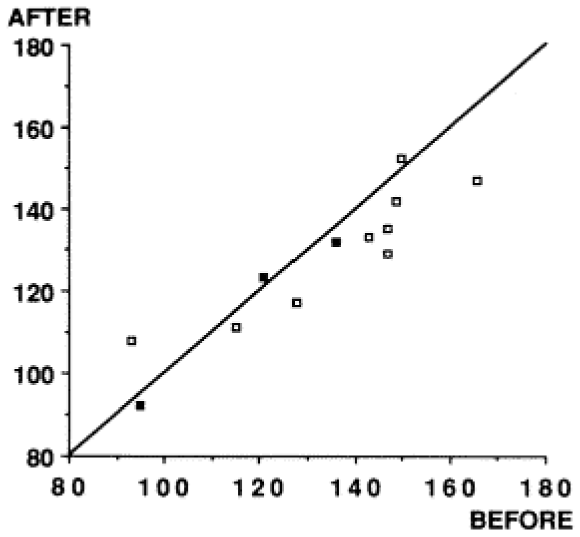

Fig 5. Heart rate (beats/min) during bicycle ergometry exercise at 70 watts before and after training, for men (solid square block) and women (outline square).

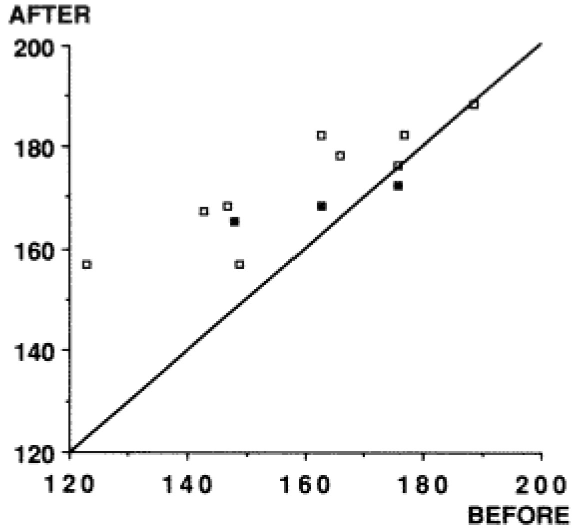

Fig 6. Maximal heart rate (beats/min) at bicycle exercise before and after training, for men (solid square block) and women (outline square).

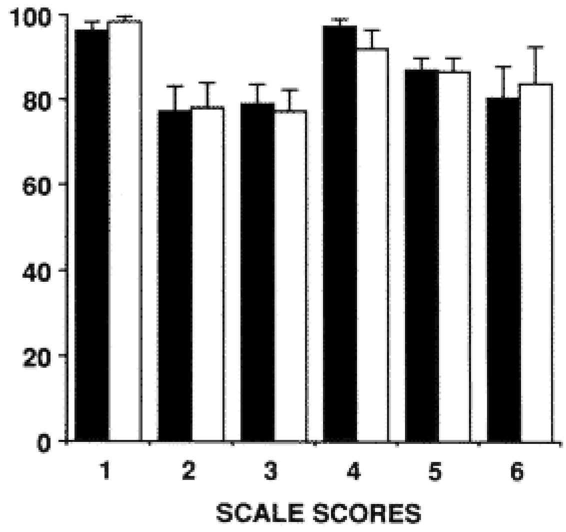

Fig 7. FSQ scale scores (mean values and standard error of the mean) for (1) Primary (basic) ADL, (2) Instrumental ADL (Mobility), (3) Mental function (well-being), (4) Social activities, (5) Social interaction, and (6) Work in the FSQ*[23]* before (solid bar) and after (outline bar) training.

DISCUSSION

Compared to the general population, most patients in this study were quite weak. The average reduction in strength was down to 60% of normal values.*[17,26]* However, the present group of subjects were not as weak as the polio subjects in an earlier study*[17]* and they were somewhat more mobile.

The CS activity showed a large individual variation from subject to subject. Most values were in the same range as in clinically healthy elderly studied in our laboratory.*[27]*

The mean fiber area in relation to our control values*[17]* and unpublished observations was increased before training and to the same magnitude as has previously been reported. Further increase in size in some subjects (Fig 3, 4) demonstrated that these muscles may still possess the ability to adapt to a training program. The program was mainly of endurance-type activities, but included exercises that require relatively high-performance forces.

One of the hallmarks of reinnervation is fiber-type grouping as was found in all present subjects, indicating that all biopsied muscles were affected by polio. The histopathologic findings did not change after exercise. In that respect, the training sessions did not cause any deleterious effect. However, two individuals were found to have a decrease in muscle strength as well as of fiber area (fig 4).

In the subjects who showed an increase in mean fiber area as well as strength, the increase in fiber area was at least four times greater than the increase in strength (fig 4). This may indicate lack of comparable increase in contractile properties and/or nonhomogeneous changes in the muscle. There were variations in the training effects on different muscle groups, which may be due to different factors such as different training intensity, sensitivity of the myometry technique in different muscle groups, and variations in pretraining muscle function and, thus, trainability as discussed above.

A cardiovascular training effect was seen in most subjects as the heart rate at a submaximal workload decreased after training. It has been suggested that a 3- to 6-

month program must be completed to be beneficial.[7] It has also been demonstrated that an aerobic training program can improve overall function without a loss of strength as seen in the present study. The fatigue test of knee-extension also showed an improvement with training.

We conclude from this study that postpolio subjects may benefit from an endurance training program and that there appears to be no harmful short-term effects in the muscle. The program emphasized submaximal resistance exercises, which may be one of the explanations for the limited training effect on muscle strength. In subjects with weaker muscles than in the present group, it may be beneficial to strengthen them before, or in conjunction with, an endurance program.[11] In such a group, an improvement of oxidative enzymatic capacity in the muscle (such as an increase in citrate synthese) would be beneficial to reduce fatigue. However, in the present group, the activity pattern before training was adequate to maintain the muscle CS levels within normal range in most subjects. Changes in CS level and central circulatory capacity by training may not be directly related.[28]

The scores in the FSQ did not show any change with training. This indicates that there were either no, minor, or nondetectable changes in the degree of difficulty with daily activities and in the impact of mental function and social contacts with training. Still, the FSQ data demonstrate that this group of patients has difficulties with instrumental (mobility) activities of daily living.

We found marked individual variations in the training response in these subjects, even in a fairly homogeneous group of postpolio subjects, who have light or moderate walking difficulties and can participate in a group training program. This further substantiates the difficulty in choosing the proper exercise level for an individual to gain maximal improvement and to avoid overwork. Careful individual monitoring by clinical observations with assessment of symptoms in relation to function and repeated muscle function measurements is, therefore, necessary in physical training of postpolio subjects.

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