Strength, Endurance, and Work Capacity After Muscle Strengthening Exercise in Postpolio Subjects

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ABSTRACT. Agre JC, Rodriquez AA, Franke TM. Strength, endurance, and work capacity after muscle strengthening exercise in postpolio subjects. Arch Phys Med Rehabil 1997;78: 681-6.

Objective: To determine whether a 12-week home quadriceps muscle strengthening exercise program would increase muscle strength, isometric endurance, and tension time index (TTI) in postpolio syndrome subjects without adversely affecting the surviving motor units or the muscle.

Design: A longitudinal study to investigate the effect of a 12-week exercise program on neuromuscular function and electromyographic variables.

Setting: Neuromuscular laboratory of a university hospital.

Subjects: Seven subjects were recruited from a cohort of 12 subjects who had participated in a previous exercise study. All subjects had greater than antigravity strength of the quadriceps. Upon completion of a postpolio questionnaire, all acknowledged common postpolio syndrome symptoms such as new fatigue, pain, and weakness; 6 of the 7 acknowledged new strength decline.

Intervention: On Mondays and Thursdays subjects performed three sets of four maximal isometric contractions of the quadriceps held for 5 seconds each. On Tuesdays and Fridays subjects performed three sets of 12 dynamic knee extension exercises with ankle weights.

Main Outcome Measures: Neuromuscular variables of the quadriceps muscles were measured at the beginning and completion of the exercise program and included: isokinetic peak torque (ISOKPT, at 60°/sec angular velocity) and total work performed of four contractions (ISOKTW), isometric peak torque (MVC), endurance (EDUR, time subject could hold isometric contraction at 40% of the initial MVC), isometric tension time index (TTI, product of endurance time and torque at 40% of MVC), and initial and final ankle weight (WGT, kg) lifted. Electromyographic variables included: fiber density (FD), jitter (MCD), and blocking (BLK) from single fiber assessment and median macro amplitude (MACRO). Serum creatine kinase (CK) was also measured initially and at 4-week intervals throughout the study.

Results: The following variables significantly ($p < .05$) increased: WGT by 47%, ISOKPT, 15%, ISOKTW, 15%; MVC, 36%; EDUR, 21%; TTI, 18%. The following variables did not significantly ($p > .05$) change: FD, MCD, BLK, MACRO, and CK.

Conclusions: This home exercise program significantly increased strength, endurance, and TTI without apparently adversely affecting the motor units or the muscle, as the EMG and CK variables did not change.

MANY POLIO SURVIVORS complain of new musculoskeletal and neuromuscular symptoms, apparently related to their old poliomyelitis illness; the most frequent health complaints are fatigue and weakness and the most frequent activities of daily living (ADL) complaints are difficulty with walking and stair climbing.[1-6] Progressive loss in muscle function may be an underlying cause for these complaints, as loss of strength in polio survivors has recently been objectively documented.[7] In the clinical setting many polio survivors ask whether they might be able to positively alter the course of strength loss through an appropriate muscle strengthening exercise program.

The role of exercise in the postpolio individual is somewhat controversial. Studies performed 30 or more years ago have shown mixed results; several of these studies demonstrated that muscle strengthening exercise was beneficial,[8-12] whereas other studies showed that exercise or activity was detrimental.[13-17]

Several recent studies have shown that muscle strengthening exercise in the postpolio population increases strength and/or performance.[18-21] The strengthening exercises performed in each study were unique, but all involved intervals of exercise interspersed with intervals of rest. Although these studies found generally positive results from the exercise program, only one of them specifically examined whether the exercise could be performed without damaging the muscle, as measured by serum creatine kinase (CK) concentration, or adversely affecting the motor units, as determined by electromyographic examination.[21] In that study, however, the exercise performed did not increase muscle strength or endurance. Thus, it was not possible to state that the exercise performed increased strength while not damaging the muscle or its motor units. It has been suggested that the surviving motor units in postpolio patients undergo a continuous process of denervation and reinnervation of some of the muscle fibers within the motor units, as evidenced by an increase in jitter and/or blocking on single-fiber electromyography (EMG) or the presence of atrophic muscle fibers on histopathologic evaluation.[3,22-30] It has also been suggested that these motor units may be vulnerable to even greater denervation, if the individual is overly active.[26] It seems prudent, therefore, to assess the effect of a moderately rigorous muscle strengthening exercise on the integrity of the muscle and the surviving motor units in postpolio subjects.

The purpose of this study was to examine the effect of a specifically defined combination dynamic and isometric 12-week home muscle strengthening exercise program on muscle strength, isometric endurance and tension time index, and muscle and motor unit integrity. We specifically wished to determine whether this exercise program would increase neuromuscular function (muscle strength, endurance, and isometric

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tension time index). We also wished to determine whether improved neuromuscular function could be accomplished without adversely affecting the muscle or the motor units, as determined by measurement of serum CK and electromyographic variables.

METHODS

Subjects

Subjects recruited into this study were from the pool of 12 subjects who had participated in a low-intensity (6 to 10 dynamic and isometric knee extension muscle contractions every other day for 12 weeks) exercise program, which did not measurably increase muscle strength.[21] All subjects had completed the low-intensity strengthening exercise program at least 1 year before the onset of this more rigorous exercise program. Other inclusion criteria were: age between 35 and 65 years; good health (no significant medical diseases such as coronary artery disease, malignancy, endocrinologic disorder, or neurological disorder [other than a history of previous poliomyelitis]) by health history questionnaire; history and physical examination compatible with the diagnosis of poliomyelitis in the past,[5] electromyographic evidence compatible with a diagnosis of previous poliomyelitis in the quadriceps muscle to be strengthened (increased jitter or blocking on single fiber EMG evaluation and/or increased median macro EMG amplitude); 30 or more years since the time of the acute poliomyelitis illness; sedentary lifestyle; ability to ambulate on a level surface; quadriceps strength of at least grade 3^+ on manual muscle testing[31]; no significant patellofemoral pathology by history or clinical examination (as such would interfere with full participation in a dynamic knee extensor strengthening exercise program); and willingness to complete the study.

Seven of the 12 subjects from the previous study volunteered to participate in this study and the data reported herein are from these seven subjects. All subjects gave written informed consent to participate in this research in accordance with this university's policies on research in human subjects.

The average age of our subjects at the time of this study was 51 years (range, 43 to 62yrs). The average age of the subjects at the onset of polio was 9 years (range, 2 to 22yrs). The average time to reach maximal functional stability after the acute poliomyelitis illness was 6 years (range, 1 to 20yrs). The average duration of neurological stability following attainment of maximal recovery until the onset of new postpolio syndrome symptoms, as defined by Halstead and Rossi,[5] was 27 years (range, 13 to 38yrs). The average time since onset of new postpolio symptoms was 10 years (range, 5 to 14yrs). All seven subjects had postpolio syndrome, as defined by Halstead and Rossi[25]; and 6 of the 7 subjects acknowledged recent strength loss. As per the study criteria, all subjects were ambulatory, but one subject used an ankle-foot orthosis (AFO) and three used an AFO and a cane.

Design of the Study

The design of this study was similar to the previously described study[21] except that the exercise was performed 4 days per week and was more rigorous. Briefly, subjects were evaluated in our neuromuscular research laboratory. Subjects completed a poliomyelitis history and a health history questionnaire. A blood sample was obtained to determine the serum CK concentration, which was used as an assessment for muscle overuse.[32,33] The quadriceps muscle group selected for strengthening was the same muscle group that had undergone the low-intensity exercise in the previous study.[21] The muscle group had been affected by poliomyelitis by history and had at least 3^+ strength on manual muscle testing.[31] A dynametric assessment of the knee extensor and flexor muscle function was performed. Approximately 1 week later, both single fiber EMG and macro EMG evaluations were performed on the quadriceps muscle selected for the exercise program. In all subjects, electromyographic evidence consistent with a previous history of poliomyelitis had to be found by the electromyographer. This included increased jitter or blocking on single fiber EMG, and an increase in the amplitude of the median macro EMG.

Approximately 1 week after the EMG evaluation, the subject was seen in the research laboratory, received an exercise logbook, and was instructed in the exercise program and use of the logbook. Subjects were instructed to document in the logbook the exercise performed and any problems they might experience from the exercise, such as fatigue, weakness, or muscle or joint pain. Also, if the subjects did not exercise, they were instructed to document the reason(s) for this in the logbook. The exercise program was then initiated and performed at home. Every other week, the subject was contacted by telephone for an update on the progress of the exercise program to be certain that (1) the subject was compliant with the exercise program and (2) the subject did not experience any adverse side effects from the exercise program. Every 4 weeks the subject was evaluated in our research laboratory. At these visits, the subject was questioned about the exercise program and the exercise logbook was reviewed to be certain that the subject was compliant with the exercise program and was not experiencing any adverse response to the exercise program; a venipuncture was performed to obtain a blood sample for determination of the serum CK concentration; and isometric peak torque of the quadriceps undergoing the exercise training was evaluated to be certain that the subject was not losing strength as a result of the exercise program. Twelve weeks after the initiation of the exercise program, the subject returned to the laboratory for the final dynametric assessments, and 1 week later the final single fiber EMG and macro EMG evaluations were performed.

Neuromuscular Assessment

Details of the neuromuscular assessment are described elsewhere.[21,34] Briefly, before the onset of the exercise program, peak knee extension torque was measured isokinetically and isometrically while knee flexion torque was measured isokinetically using a dynamometer.[a] The subject performed six maximal-effort isokinetic knee extension and flexion contractions at an angular velocity of 60°/sec. The four best consecutive efforts were selected and the peak torque as well as the total work performed during the four best consecutive efforts were recorded for subsequent analysis. (The isokinetic knee flexion variables were used as quasi-control values because the hamstrings were not specifically being strengthened in this exercise program.) Isometric knee extension peak torque was then determined with the dynamometer, with the knee flexed 60° from full extension, by three 5-second maximal effort trials interspersed by 1-minute rest breaks. The average of the three trials was defined as the isometric maximal volitional contraction (MVC). Following this, an isometric endurance test was performed at 40% of MVC on the dynamometer until subjects could no longer maintain the assigned torque output. Rating of perceived exertion (RPE)[35] in the contracting quadriceps muscle was obtained at 20-sec increments from the onset of this endurance test to its completion. Surface electrodes were used to assess the electromyographic median frequency of the power spectrum of the quadriceps muscle continuously throughout the endurance test. The RPE and electromyographic power spectrum data will be reported elsewhere. The endurance time was recorded in seconds. The tension time index (TTI) was defined as the product of the isometric torque (in newton meters [Nm]) during this test and the endurance time (in seconds).

After completion of the exercise program, subjects were assessed in similar fashion as described above, except that the isometric endurance test was performed at the same absolute torque output as performed initially (and not at the new 40% of MVC).

Electromyographic Evaluation

Single fiber EMG and macro EMG, using previously described techniques,[21,36-38] were performed on the quadriceps muscles in subjects before and after the 12-week exercise program using a Teca macro and single fiber EMG needle electrode.[b] Single fiber EMG was performed on an EMG machine[c] with filter settings at 500 to 15,000Hz, a sweep speed at 0.5 to 1.0msec/division and sensitivity adjusted to determine peak-to-peak amplitude of the wave form. The signal from the macro EMG electrode was passed in parallel to Teca TD-20 EMG machine[b] specially modified to allow macro EMG analysis. Macro EMG filter settings were 2 to 10,000Hz, sweep speed was 10-msec/division, and sensitivity was adjusted to allow recording of peak-to-peak macro EMG motor unit potential amplitudes. Twenty motor units were assessed in each subject for macro EMG determinations. An attempt was made to also evaluate 20 single fiber EMG potential pairs for jitter and blocking. Because of fatigue or intolerance to the procedure, this was not always possible in all subjects.

Serum CK

A blood sample was obtained by venipuncture of the antecubital vein with the subject in the seated position at the beginning of the initial visit and at the subsequent visits 4, 8, and 12 weeks into the exercise program. The samples were sent to our hospital's clinical chemistry laboratory where they were analyzed to determine serum CK concentration using standardized techniques.[39,40]

Exercise Training Program

The exercise program was performed at home for 12 weeks. Commercially available cuffed ankle weights were used for the dynamic portion of the exercise program. The weight was placed around the distal leg just above the malleoli of the ankle. The weight could be adjusted in .23kg (0.5 pound) increments. The initial weight to be used in the strengthening exercise was individually determined. The subject sat in a chair with the weight attached just above the ankle and with the hip and knee flexed to 90° and the foot resting on the floor. The subject slowly extended the knee until it was straight, held that position for 5 seconds, and then slowly lowered the weight. In general, the subject started with a weight at the ankle of approximately 1 to 1.5kg. After each repetition the subject was asked to provide his or her RPE.[35] The weight was gradually increased until the RPE was 13 to 14 (a rating of "somewhat hard" [RPE = 13] or somewhat greater, but less than "hard"[RPE = 15]). This was determined to be the starting weight for the subject. The amount of weight was then adjusted by telephone during the first 2 weeks of the exercise program. For each exercise set, the subject slowly fully extended and then immediately lowered the weight over a 5-second interval with no rest between the 12 repetitions in the set. After completion of each set of twelve repetitions, the subject rested for 1 minute. After completion of the third set of twelve repetitions, the subject rated the RPE in the exercised quadriceps muscles. If the RPE was less than 19 (a rating of "very, very hard"), the ankle weight was increased at the next exercise session. The increments of weight added were individually determined, but were usually at .23 to .46kg (0.5 to 1.0 pound) increments. These exercises were performed on Tuesdays and Fridays.

On Mondays and Thursdays, the subject performed three sets of four maximal-effort isometric contractions of the quadriceps muscles held for 5 seconds during each repetition. The subject rested for 10 seconds between each repetition within a set and for 1 minute between each of the three sets. For this exercise the knee was placed at 60° from full extension (using a simple plastic two-armed device with the arms set at a 60° angle) with the toe of the shoe placed against an immovable object such as a wall.

The subject was also given an exercise log book at the time of the initial evaluation. After every exercise session, the subject recorded the exercises done and indicated whether or not there were any problems with the exercise such as fatigue, weakness, or muscle or joint pain. If the subject was unable to exercise, the reason was recorded. Compliance with the exercise program was made by evaluation of the log book entries.

After 4 and 8 weeks of exercise, the subject performed one exercise session in the research laboratory. On these days, the subject's exercise consisted of 10 5-second maximal isometric contractions of the quadriceps on the dynamometer using the same isometric technique as during the initial evaluation. One-minute rest breaks were provided between efforts. The average of the first three efforts was recorded to compare with the initial measurements to be certain that the subject was not losing strength as a result of the program. These data were also recorded for subsequent analysis.

Statistical Analyses

The Wilcoxon matched-pairs test[41] was used to compare the preprogram values to the postprogram values. A Friedman repeated measures analysis of variance (ANOVA)[42] was used to evaluate values that were measured on more than two occasions (ie, the serum CK and isometric MVC variables). When appropriate, Holm's post hoc comparisons were conducted to determine differences between measures. All results are expressed as mean ± SD in the text and tables. For all analyses statistical significance was defined as $p < .05$.

RESULTS

Exercise compliance. Compliance with the exercise program, as determined from the exercise recordings in the exercise log books, was excellent. Each subject was assigned 48 exercise sessions. Subjects were asked to exercise four times per week, as per the protocol, but were allowed to miss an exercise session if they felt ill. Of a possible 336 exercise sessions for the total group, 330 of the sessions were reported as completed (98.2% exercise compliance). Illness was the only reported reason for any subject to miss an exercise session. One subject had reported anteromedial knee pain while performing the dynamic knee exercise at the onset of the exercise program; however, this subject was hyperextending the knee and was also performing the exercise with the hip slightly externally rotated. Both of these added stress to the anteromedial aspect of the knee and caused the mechanical pain. When the training error was corrected, the knee pain resolved within 1 week and did not recur. None of the other subjects acknowledged any problems (such as muscle or joint pain) as a result of participation in the exercise program.

Measures of neuromuscular function. All subjects increased the amount of weight lifted during the dynamic component of their exercise program and the mean change was statistically significant ($p < .05$) (table 1). The mean initial and final

Table 1: Mean ± SD Neuromuscular Variables of the Seven Subjects Before and After Completion of the 12-Week Exercise Program

	Before	After	Percentage Change
Ankle Weight Lifted (kg)	7.8 ± 2.8	11.5 ± 2.8*	47%
Isometric Quadriceps			
Peak Torque (Nm)	98 ± 63	134 ± 65*	36%
Endurance Holding Time (sec)	142 ± 46	172 ± 50*	21%
Tension Time Index (Nmsec)	6,090 ± 2,280	7,200 ± 2,240*	18%
Isokinetic			
Quadriceps Peak Torque (Nm)	73 ± 36	85 ± 41*	15%
Quadriceps Total Work Performed (Nm)†	306 ± 148	354 ± 170*	15%
Hamstrings Peak Torque (Nm)	41 ± 24	45 ± 25	9%
Hamstrings Total Work Performed (Nm)†	171 ± 89	173 ± 96	1%

* $p < .05$ comparing before and after.
† Isokinetic total work (Nm) during four successive muscle contractions performed at an angular velocity of 60°/sec.

values for dynametrically determined isometric strength as well as endurance holding time and tension time index variables are also shown on table 1. All of the isokinetic quadriceps variables were also significantly ($p < .05$) increased after the exercise program as compared to beforehand. The hamstring variables, however, did not significantly ($p > .05$) change during the program. The Friedman two-way ANOVA also showed a significant ($p < .05$) increase in isometric strength from the time of the initial assessment through the end of the exercise program as measured in the laboratory every 4 weeks.

Electromyography. The mean electromyographic variables before and after the 12-week exercise program are listed in table 2. None of these values significantly ($p > .05$) changed.

Serum CK. Some of the serum creatine kinase data was missing for 2 of the 7 subjects; therefore, complete data sets were obtained on 5 of the 7 subjects. The mean ± SD of the values from these five subjects did not significantly ($p > .05$) change from study onset through 4, 8, and 12 weeks of exercise and were 118 ± 44, 127 ± 66, 137 ± 49, and 147 ± 92U/L, respectively. These mean values were well within the reference values for our hospital's chemistry laboratory (normal range of 0 to 250U/L in men and 0 to 175U/L in women).

DISCUSSION

The present study examined the effect of a 12-week muscle strengthening exercise program on muscle strength, isometric endurance and tension time index, and muscle and motor unit integrity in a quadriceps muscle, which was affected by poliomyelitis decades earlier in a cohort of seven postpolio subjects. The characteristics of the subjects in this study are similar to that of other postpolio groups reported in the literature. The average age of our subjects at the onset of polio, the average time to reach maximal functional stability after the acute illness, the average duration of neurological stability before the onset of new postpolio syndrome symptoms, and the average time since onset of new postpolio symptoms were all similar to those reported previously.[1,5] Electromyographic assessment of our subjects showed increased jitter and/or blocking by single fiber EMG and an increase in median macro EMG amplitude, which was similar to postpolio subjects in other reports.[28,29] Strength of the quadriceps femoris musculature, as measured isometrically, in our postpolio subjects was also similar to that reported in postpolio subjects studied by Einarsson and Grimby.[19,43]

All of the subjects in this study were weak. The average pre-exercise strength of our postpolio subjects was just under half of the expected value, as compared to values obtained in control, nonpolio subjects, in similar fashion in our laboratory.[34] Despite the significant weakness found in our subjects, all of these subjects completed the exercise program without any new complaints of weakness, fatigue, or other adverse effects.

Neuromuscular function of the quadriceps femoris muscle was found to significantly increase after the completion of the exercise program in our subjects. On the average, isometric peak torque of the quadriceps increased 36%, isometric endurance holding time increased 21%, isometric tension time index increased 18%, and the isokinetic peak torque and total work performed during four successive contractions each increased 15%. Thus, the subjects became stronger, had improvement in muscular work performance, and had improvements in endurance capacity and the tension time index, apparently as a result of the performance of this exercise program. In the previously performed low-intensity exercise program performed by these subjects, none of the neuromuscular variables significantly changed.[21] The improvement in the tension time index was related to the improvement in the isometric endurance time. We are inclined to believe that the improvement in the isometric endurance holding time was related to the performance of the endurance task at a lower relative torque output after completion of the exercise program as compared to before the exercise program. Because of the average increase in isometric strength of our subjects (36%), the isometric endurance test was performed at approximately 30% of MVC after the exercise program as compared to 40% of MVC before the exercise program. Many years ago Rohmert[44] demonstrated that isometric endurance time was related to the relative level of effort of the working muscle. The maximum holding time was shown to increase as the relative level of effort decreased from a full 100% effort towards minimal effort. Our data are consistent with Rohmert's report.

It is important to point out that one of the flaws of our study is that it was not a controlled experiment. Because the number of subjects recruited was small, all subjects were recruited to participate in an exercise program. Thus, we had no control group. For this pilot study, we did assess the isokinetic peak torque and total work performed of the hamstring muscles in the same limb as the quadriceps muscles being exercised. These data were utilized as quasi-control values. We believed that this approach was reasonable for this pilot study because the ipsilateral hamstring muscles were not being exercised in this study. Because our analyses showed no change in hamstring strength after the 12-week exercise period while quadriceps strength significantly increased, we are inclined to believe that the most probable reason for the increase in neuromuscular function in the quadriceps was the exercise program and not some other factor.

In addition to finding a significant improvement in neuromuscular function of the quadriceps muscles in these subjects, no evidence was found to indicate that the exercise program was detrimental. Although one subject reported transient knee pain at the onset of the exercise program, it was related to a training

Table 2: Mean ± SD EMG Variables of the Seven Subjects Before and After Completion of the 12-Week Exercise Program

	Before	After
Single Fiber EMG		
Fiber Density	1.9 ± 0.3	2.0 ± 0.4
Blocking (%)	23 ± 12	19 ± 10
Jitter (usec)	87 ± 31	72 ± 20
Macro EMG Amplitude (mV)	1.5 ± 0.9	1.4 ± 0.5

No variable was significantly ($p > .05$) different after the exercise program as compared to before the program.

error. The knee pain quickly resolved when the training error was corrected and did not recur. No other subject acknowledged any problems (such as fatigue, weakness, or muscle or joint pain) as a result of participation in the exercise program. Additionally, no change was found in serum CK concentration throughout the duration of the exercise program. Had the exercise program been too vigorous and caused muscle fiber damage, evidence of this injury, as reflected by a significant increase in the serum CK concentration, would have been expected. It is well known that serum CK substantially increases when muscle fibers are damaged.[45,46] Further, the electromyographic assessment revealed no changes in any of the electromyographic variables assessed (macro electromyographic amplitude and fiber density, blocking, and jitter on single fiber electromyography). Hypothetically, one may have expected to see evidence of damage to the surviving motor units within the muscle if the exercise program had been too vigorous. Although no prospective human studies have been performed to evaluate the effect of excessive exercise on the motor units, had the exercise performed by our subjects been sufficiently excessive to cause denervation of some of the muscle fibers within the surviving motor units, one may have expected to observe some changes in the motor units variables assessed by the two electromyographic techniques employed. In particular, macro EMG evaluation would have been expected to show a decrease in the median macro EMG amplitude if some of the muscle fibers in the motor units had become denervated as a result of the excessive activity and no reinnervation had occurred. Single fiber EMG evaluation would have been expected to show an increase in jitter and blocking if some of the muscle fibers within the motor units had undergone denervation and reinnervation, because the newly formed myoneural junctions would have been immature, which would have been manifested by an increase in jitter and blocking.

With our report, there are now three studies in the literature that have shown significant improvement in muscle strength in postpolio patients through a therapeutic exercise program without apparent deleterious effects. Einarsson and Grimby[19] reported a 16% to 17% increase in isokinetic and isometric strength of quadriceps muscles in 12 postpolio patients. The patients underwent an exercise program three times a week for 6 weeks. The exercise program performed by the subjects was supervised in their research laboratory on a special dynamometer and was a combination of isokinetic and isometric exercise. The average initial quadriceps strength of these subjects was very similar to the subjects in our study and the rate of isometric strength gain was also similar between our two studies. Safety of the exercise program was assessed by muscle biopsies, which were performed before and after the exercise study. No evidence of muscle damage was found histopathologically in these subjects and none of the subjects complained of discomfort with the exercise program. Recently, a study by Spector and colleagues[47] reported the effect of a dynamic progressive resistive exercise program on the strength of the quadriceps femoris and triceps brachii muscles in six postpolio subjects. Under supervision, the subjects performed three sets of progressive resistive exercises per exercise session three times per week for 9 weeks. The subjects in the study by Spector and associates[47] appeared to be much stronger than the subjects in our study or in the study of Einarsson and Grimby,[19] as the initial average strength of the knee extensors was over twice that of either of our groups of patients. Spector and collaborators[47] reported that muscle strength, as determined by the maximum amount of weight the subject could lift three successive times, increased by an average of 41% and 61% for leg press and knee extension, respectively, and by an average of 54% and 71% for arm press and arm extension exercises, respectively. Muscle strength, as determined isometrically, however, did not change in the arm or leg musculature, and the authors stated they believed this to be due to the principle of specificity of training. Muscle biopsies were obtained before and after the exercise program and serum CK was obtained at regular intervals throughout the exercise program. No evidence of damage from the exercise program could be found by muscle histopathological evaluation or serologically (as the concentration of CK did not increase in any of the subjects during the exercise program). Also, none of the subjects complained of muscle pain or soreness during the exercise training program. In our study, no change was found in the serum concentration of CK, none of the electromyographic variables was noted to change, and none of the subjects acknowledged muscle soreness or other problems with their exercise program (other than the one subject with the temporary knee pain due to a training error).

It should be pointed out that although our results are encouraging, they should be viewed cautiously because the statistical power to determine adverse effects of exercise (change in electromyographic variables and serum CK concentration) was low. Three independent studies, however, have now assessed the safety of muscle strengthening exercise in postpolio patients. The exercises performed in each study were unique, but all entailed a supervised exercise program and all resulted in significant increases in muscle strength. Two studies were performed under direct supervision in a research laboratory[19,47] and one (our study) was performed primarily at home with visits to the research laboratory every 4 weeks and telephone contact every 2 weeks. Safety was also assessed differently in each study. Einarsson and Grimby[19] assessed for deleterious effects histopathologically, Spector and coworkers[47] assessed for deleterious effects histopathologically and serologically, and our study assessed for deleterious effects serologically and electromyographically. Also, none of these three studies reported any untoward effects from the performance of the exercise program, such as progressively increasing muscle or joint pain. It thus appears that postpolio patients may be able to safely strengthen muscles with greater than antigravity strength when reasonable precaution is taken. Further studies are needed, however, to determine whether the strength gains will increase the individual's ability to perform routine daily activities, and the long-term efficacy of such intervention in postpolio patients is yet to be assessed.

CONCLUSION

This exercise program significantly increased muscle strength, work performance, endurance, and isometric tension time index without apparently adversely affecting the motor units or the muscle, as the electromyographic and serum CK variables did not change.

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Suppliers

a. Lido Active Dynamometer; Loredan Biomedical, Inc., 1632 DaVenci Court, PO Box 1154, Davis, CA 95617.
b. Teca EMG macro/single fiber EMG needle; Teca TD-20 EMG machine; TECA, 3 Campus Drive, Pleasantville, NY 10570.
c. Tracor Northern, Inc., 2551 W. Beltline Highways, Middleton, WI 53562.