National Rehabilitation Hospital Limb Classification for Exercise, Research, and Clinical Trials in Post-Polio Patients

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The appropriate role of exercise for post-polio patients presents a clinical and research dilemma. It is well known from muscle physiology that exercise of various types improves both muscle strength and endurance. Following episodes of acute paralytic polio, patients often went through long periods of exercise training and re-education to regain the muscle strength and mass they had lost. In fact, exercise was frequently viewed as the "cure" for paralytic polio and if one did enough exercises, the belief of many patients was they could "overcome" or beat polio.

Now decades later, many persons who had paralytic polio are experiencing new weakness in muscles previously affected by polio as well as muscles felt to be unaffected.*[1]* Because the initial theories concerning new weakness focused on a dysfunctional or deteriorating motor neuron that was already overextended, the preliminary belief among most clinicians was that appropriate management of these overused motor units would minimize further overwork.*[2-5]* This meant either no exercise or, at the most, very limited exercise.

Although the exact cause of late-onset weakness in polio is still not completely understood and, in fact, may represent the result of several processes acting separately or together, it is now becoming clear that new muscle weakness in many persons may have a reversible or "treatable" component that responds well to certain types of exercise.*[6-8]* However, it is also clear that the same exercise program cannot be prescribed to each individual because the extent of involvement and possibly the cause of new weakness may vary from individual to individual as well as from limb to limb within the same person. In addition, in the absence of more precise information concerning each individual's history and possible cause of new weakness, it may be inappropriate to adapt exercise guidelines from a heterogeneous research group to an individual patient in a clinical setting. Similarly, without a standard nomenclature for each individual or limb, it is difficult to compare the effectiveness of one exercise program reported in the literature to another. The patient descriptors currently in use, "symptomatic" and "asymptomatic,"*[8,9]* or in some

cases, "with and without post-polio syndrome,"*[5-7]* do not provide enough information to adequately distinguish patients or, more precisely, to distinguish limbs, with very different histories, physical exams, and electrodiagnostic findings.

For these reasons, we developed a limb-specific exercise classification to make exercise prescriptions in the typical clinical setting more rational and systematic. In addition, it is anticipated that such a classification would be very useful in clinical research trials testing the impact of various medications or new exercise protocols. It is our hope that use of this classification will give us a common language and make it possible to compare more accurately the results of different types of interventions applied to the same class of limbs - in other words, to be able to compare like with like. The classification is based on both remote and recent history, a physical examination, and electrodiagnostic studies (EMG/NCS). Using this classification, we report the results of a prospective study and present several case histories as well as a list of proposed exercises appropriate for each level of classification in both clinical and research settings.

METHODS

One hundred consecutive post-polio patients were evaluated with a comprehensive history and physical examination performed by one of two physicians.*[10]* As part of the evaluation each patient underwent a four-extremity electrodiagnostic screening examination, which included a nerve conduction study (NCS) of bilateral median and ulnar sensory nerves as well as a needle electromyograph (EMG) protocol of three muscles in each extremity. In the upper extremity, the biceps, triceps, and first dorsal interosseous or abductor pollicis brevis were studied. In the lower extremity, the quadriceps, tibialis anterior, and the gastrocnemius were examined. Additional limb muscles as well as lumbar and cervical paraspinals were studied as clinically indicated.

Using this combination of history, physical examination, and EMG data, we evaluated each limb and assigned it to one of the five classes according to the most severely involved muscle. The classification of each limb was determined, in turn, by five elements: (1) history of weakness at the time of acute polio; (2) the presence or absence of new weakness; (3) current strength on manual muscle testing; (4) the presence or absence of old and/or new atrophy; and (5) the presence or absence on electromyogram (EMG) of findings consistent with remote anterior horn cell disease (AHCD).

The National Rehabilitation Hospital (NRH) Post-Polio Limb Classification consists of five classes summarized in TABLE 1. NRH Class 1 limbs (no clinical polio) contain those muscles without obvious evidence of polio. There is no remote history of weakness in these limbs and no new weakness. Strength ranges from good to normal, there is no atrophy, and reflexes are normal. The screening EMG of key muscle groups as described is normal, with normal insertional activity (IA) and no evidence of muscle membrane instability (fibrillations [fibs] or positive sharp waves [PSW]). Motor unit action potentials (MUAPs) are normal in size and configuration, with full recruitment. In defining Class I limbs, if every muscle were studied exhaustively, the possibility of finding some abnormalities on EMG compatible with old polio would be quite high. Because this is not practical in most clinical and research settings, we adopted the convention of using a standardized sampling technique. Clearly, if the physical examination suggests involvement of other muscle groups, they should be included in the EMG evaluation of that limb.

TABLE 1. National Rehabilitation Hospital Post-Polio Limb Classification	
Class I	No clinical polio
Class II	Subclinical polio

Class III	Clinically stable polio
Class IV	Clinically unstable polio
Class V	Severely atrophic polio

NRH Class II limbs (subclinical polio) present with either no remote history of weakness, or if paresis was present, there was eventually full clinical recovery.*[1,4,11,12]* There is no history of new weakness or atrophy, strength is in the good to normal range, and reflexes are normal. On EMG, IA is normal and no fibrillations or PSW are observed. MUAPs are slightly larger than normal with increased polyphasics and decreased recruitment.

NRH Class III (clinically stable polio) are those limbs with stable strength. There is a history of remote weakness in one or more muscles in these limbs, with incomplete recovery, but no complaints of new weakness or atrophy. On physical examination the strength ranges from fair to good, and reflexes are normal or decreased. Chronic atrophy may be present. On EMG, IA is normal and sometimes there are fibs or PSW, but generally these are small and sparse. MUAPs are large with increased polyphasics and up to 50% decrease in recruitment.

NRH Class IV limbs (clinically unstable polio) are similar to Class III limbs; there is, however, a history of new weakness and possibly atrophy. They are generally weaker, with less dynamic and isometric strength than Class III.*[9]* Atrophy is often present and reflexes tend to be decreased proportional to the weakness. EMG findings are similar to Class III; however, MUAP amplitude and percentage of polyphasics may be increased.*[9]* Recruitment is further reduced and more fibs may be seen.*[13]*

NRH Class V limbs (severely atrophic polio) are those limbs that are severely atrophic. The major muscles in these limbs had remote weakness and little-to-no improvement. New weakness may be present; however, the muscles in these limbs are already so weak it is hard to tell. On physical examination, the major muscles are extremely weak with marked atrophy and diminished-to-absent reflexes. On EMG there is decreased IA, fibs or PSW may be present, little-to-no MUAPs with variable amplitude, increased polyphasics, and markedly decreased recruitment.*[12,14]* In general, there is little functional use of these extremities.

GUIDELINES FOR CLASSIFICATION

For purposes of using this classification, we have adopted several rules or guidelines. These include: (1) each major muscle is classified separately; (2) the limb is classified according to the most affected muscle; (3) Class I and V limbs do not change; (4) limbs in other classes may change, for example, Class II limbs may progress to Class III (though not commonly), and Class III limbs frequently progress to Class IV limbs; and (5) Class IV limbs can sometimes revert to Class III limbs with proper management. As with any classification system, each object (limb) can be assigned to one and only one class and no limb can be without a class. Theoretically, one could classify each major muscle in each limb which would provide a more precise picture of that extremity. However, it would make the classification system and process considerably more cumbersome and would defeat one of its central purposes, notably, to create a simple, easy-to-use taxonomy.

RESULTS

We classified 400 limbs in 100 consecutive post-polio patients. TABLE 2 shows the demographic characteristics of this population. There were 62 females and 38 males with a mean age of 55 years, ranging from 22 to 82 years. They had a mean of 43 years since polio with a range from 10 to 80 years. The results of classifying the 400 limbs in these 100 patients is shown in TABLE 3. Each limb was assigned to only one class using the criteria outlined above and no limbs could not be classified. There were 94 (23%) Class I limbs, 88 (22%) limbs in Class II, 95 (24%) limbs in Class III, 75 (19%) limbs in Class IV, and 48 (12%) limbs assigned to Class V. The frequency distribution of upper and lower extremities by class is shown in FIGURES 1 and 2. As others have found, there was a preponderance of more severely involved limbs in the lower extremities.*[15,16]* Seventy-two percent of the legs were in Classes III, IV, and V compared with 37% of the arms in these same three classes.

TABLE 2. Demographic Data on 100 Consecutive Post-Polio Outpatients.

Sex (*n*)	Age (years)	Years Post-Polio
Male (38)	Mean: 55	Mean: 43
Female (62)	Range 22-82	Range 10-80

TABLE 3. NRH Limb Classification of 100 Consecutive Post-Polio Outpatients.

NRH* Class	Upper Extremity	Lower Extremity	Total**
I	84	10	94
II	42	46	88
III	42	53	95
IV	25	50	75
V	7	41	48
Total	200	200	400

* NRH, National Rehabilitation Hospital.
** Number of limbs classified = 400.

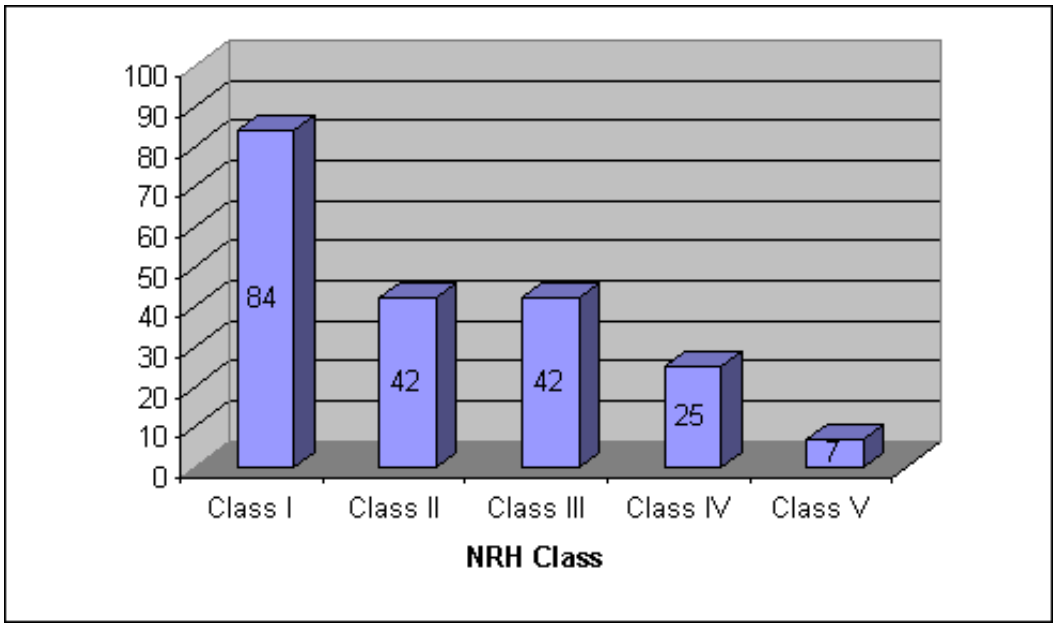

FIGURE 1. Frequency distribution of upper extremity limbs by class in 100 consecutive post-polio outpatients (n = 200).

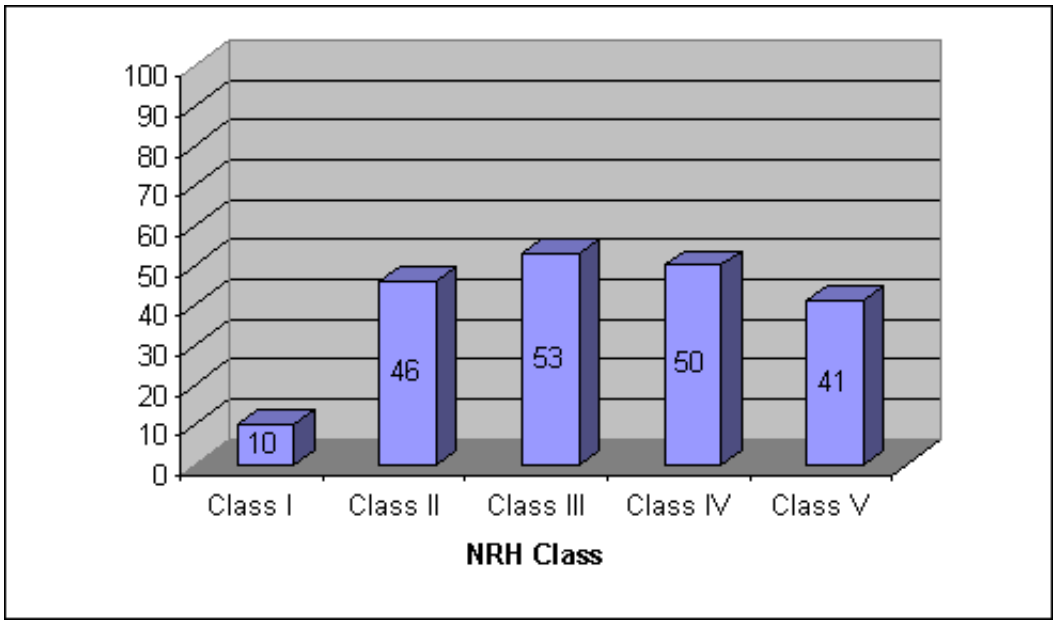

FIGURE 2. Frequency distribution of lower extremity limbs by class in 100 consecutive post-polio outpatients (n = 200).

CASE HISTORIES

Case 1

L.D. is a 67-year-old semiretired man who had acute, paralytic polio at age four in 1930. According to his recollection and that of his parents, he experienced mild weakness of only the left leg. His recovery was good and during school years he was able to keep up with his classmates in outdoor activities. Although he denied any impediment as an adult, his wife noticed a slight limp especially when he was tired.

In 1985, at the age of 59 --55 years after his original polio-- his limp became more pronounced, he started falling on occasion, and lie was aware of his left knee going into recurvatum as a way of stabilizing his leg.

In 1993, he presented at the clinic with complaints of easy fatigue on walking, pain in his left quadriceps with activity, and occasional tripping on curbs and stairs. He denied joint pain, new atrophy or generalized fatigue, and his past history was unremarkable except for hypertension controlled by medication. Physical examination was pertinent for fair+ strength in all major muscle groups of the left leg except the quadriceps, which were poor. Deep tendon reflexes were diminished in the left leg and sensation was normal. There was no significant leg length discrepancy, and the remainder of the physical exam was unremarkable except for compensatory hypertrophy and strength in the muscles of the right leg. Electrodiagnosis revealed changes compatible with old polio confined to the left leg. The rest of the exam was normal including evaluation of the lumbar paraspinal muscles.

Comment. This patient presents several interesting features with respect to his exercise management and the application of the limb classification. (1) Even though his initial polio involvement was felt to be mild and confined to one major muscle group in one limb, his subsequent history and physical exam made it clear he had significant involvement of all major muscle groups in his left leg. (2) Based on our experience and that of many others, the degree of disease in the left lower extremity strongly suggested that the right lower extremity would also show subclinical polio changes on EM exam. To our surprise, no "traces"of remote polio were found by EMG in that limb in the three key muscles examined. (3) These findings expanded his exercise options and made it possible for us to recommend an aerobic exercise program that involved three of his four extremities. His limbs were classified as follows: both arms and the right leg were Class I and the left leg was Class IV. His rehabilitation management included a long leg brace (LLB) on the left to stabilize his ankle and knee joints and a cane in his right hand to reduce weight bearing on the left leg and improve his overall stability. Because he still worked part-time as a consultant and had a busy schedule, we prescribed an upper extremity ergometer that he used 20-30 min a day at 80% of his maximum heart rate (HR max) three to four times a week at home. During the warm weather, he used a community pool on alternate days to swim laps for 20 min using a floater to support his weak left leg. Without the classification, we would have discouraged any formal exercise involving the right leg and been unsure what guidelines to give him for his arms.

Case 2

S.R. is a 46-year-old woman university professor who had acute polio at age 8 in 1955. She had paresis of both legs, more marked on the right than the left, but denied any weakness in her arms or difficulty with breathing or swallowing. She wore a LLB on the right leg through junior high school and then walked without any assistive device except for an occasional cane in the left hand.

In 1993, at the age of 46 --38 years after the onset of acute polio-- she presented in our clinic with a

history of three to four years of progressive weakness of the right leg and generalized fatigue that came on in the mid-to-late afternoon. She had muscle and joint pain in the right leg with weight-bearing activities and noticed new atrophy in the right thigh one year before coming to the clinic. The remainder of the history was unremarkable except for a hysterectomy in 1989. Physical examination was pertinent for fair-to-fair+ strength in all major muscle groups in the right leg and fair-to-good strength in major muscle groups in the left leg. There was moderate atrophy of the right leg and scattered atrophy in the left. Deep tendon reflexes were diminished consistent with decreased strength. Sensation was normal but there was a ¾-inch leg length discrepancy and mild scoliosis concave to the right. Strength, sensation, and reflexes were normal in the upper extremities, and the remainder of the physical exam was unremarkable. Electrodiagnostic studies revealed changes compatible with old polio throughout both legs and scattered giant motor units in both arms.

Comment. The evidence of old polio by EMG in the left leg was predictable; findings compatible with old

polio in the patient's arms were unexpected but not unprecedented. In fact, it was just these kinds of unexpected findings that led us to develop a screening four-limb EMG protocol that is now a standard part of the evaluation of new patients in our clinic. Classification of this woman's limbs were as follows: both arms were Class II (subclinical), the left leg was Class III (stable), whereas the right leg was Class IV (unstable). Her rehabilitation management included a LLB on the right along with a ¼-inch heel lift that was gradually increased to ¾ inches, a manual wheelchair for long distances, an afternoon rest break, and pacing of her daily activities with an emphasis on avoiding prolonged standing and walking. Because we were concerned about the possibility of new weakness developing in the left leg, we recommended that she use forearm crutches for long distance when a wheelchair was impractical. However, she opted for a cane in the left hand for the time being. We did not give her any formal exercises for her "good" left leg as it was already getting a substantial workout every day in the course of her normal routine, and it was our belief that adding a structured exercise program on top of a full day of activities was inviting additional new muscle weakness. Although her arms looked and felt normal, the positive EMG findings made us reluctant to exercise her arms as though they were normal. Instead, our approach was to prescribe aerobic exercises with less intensity and duration than for Class I or normal limbs. In this case the patient was put on an all exercise program using an upper extremity ergometer at 60-80% of HR max for 15-20 min a day on alternating days three times a week. We felt that normal walking at home and work provided adequate exercise for her legs, especially the right, and we also recommended handicapped plates. The value of the classification in this case was to alert us to the presence of subclinical polio in her arms which helped guide us in prescribing slightly less rigorous exercises than we might otherwise have given her. In addition, it helped guide us to a more conservative approach in the management of the "good" left leg.

Case 3

W.T. is a 44-year-old male stockbroker who had vaccine-related polio at age 21 in 1970. He experienced weakness in both legs and his left arm but had a good clinical recovery that reached a neurological and functional plateau three years later at the age of 24. He presented at the clinic in 1993, 24 years following his acute episode, with no particular problems but was interested in a general evaluation and recommendations concerning his future management. Pertinent findings on physical exam included good-to-normal strength in his left arm, normal strength in his right arm, normal strength in his left leg, and good-to-fair strength in the hip and knee muscles of his right leg. The right dorsiflexors were poor and the plantar flexors were trace. Muscle bulk and reflexes were compatible with these findings, and the remainder of the exam was unremarkable. Electrodiagnosis showed changes consistent with old polio in all four limbs.

Comment. This patient is presented to illustrate an important exception in applying the rules for deciding a limb classification. Because there was reduced strength but no new weakness in his left arm, it was assigned to Class III. His right arm and left leg had normal strength and bulk but evidence of subclinical polio on EMG, and therefore were both classified in Class II. His right leg provides the exception. According to the classification guidelines, one normally classifies a limb based on the weakest major muscle or group of muscles. In the case of this patient, the weakest major muscles were his tibialis anterior and the triceps surae which were in the trace-to-poor range. The weakness and associated atrophy of the muscles of the foot and ankle would ordinarily place this limb in Class V. However, by using a short leg brace, it was possible to readily stabilize the foot and ankle and compensate for much of the lost strength and function in that limb. When this is possible, the remaining muscles can be exercised more normally and the classification then depends on the strength of the other muscles. In this case, the muscles of the hip and knee were in the good-to-fair range with no new weakness; therefore, the limb was reclassified in Class III. Exercises were prescribed based on Class III guidelines, and the patient was encouraged to favor his stronger Class II limbs whenever possible.

DISCUSSION

There are several pathophysiologic features of paralytic polio which distinguish it from other neurological disorders and which make it difficult to predict easily and reliably the absence or extent of involvement in a particular muscle or an individual limb 30, 40 or 50 years after the initial disease. These features include (1) the focal, asymmetric involvement of motor neurons throughout the nervous system; (2) the high percentage of infection of anterior horn cells during the acute illness which Bodian found was commonly as high as 95%;*[17]* (3) the fact that some anterior horn cells could become infected and then recover, although possibly still harboring some permanent impairment; (4) the fact that patients could experience substantial involvement of muscles that would not be apparent to either themselves or their physicians but would show evidence of involvement by EMG many years later; and (5) the observation that many patients experienced various degrees of involvement of a limb that later became, for all practical purposes, normal in strength, appearance, and function.

It is because of these pathophysiologic features of polio that exercise prescriptions must be applied cautiously and within an objective, scientific framework. Limbs that have normal strength and mass cannot be assumed to be "polio free" anymore than limbs felt to be unaffected originally (by history and muscle testing) can be assumed to be uninvolved.

Based on this rationale, we believe a screening EMG exam is essential before a polio subject undertakes a formal exercise program. However, even more basically, we feel it is crucial that an objective, standard taxonomy be developed for classifying each limb in patients with paralytic polio. As with other diseased (or disease-free) organs, a standardized taxonomy provides a means of establishing a common language that can be used by clinicians and researchers alike. This makes it possible to establish an objective baseline before initiating treatment and then apply a systematic, rational protocol appropriate for each class. When results of various protocols and clinical trials are then compared, we have a better basis for understanding their efficacy and their applicability to other patients (or limbs) with similar involvement.

SUMMARY

A need exists for an objective classification of polio patients for clinical and research purposes that takes into account the focal, asymmetric, and frequent subclinical nature of polio lesions. In order to prescribe a safe, effective exercise program, we developed a five-level (Classes I-V) limb-specific classification system based on remote and recent history, physical examination, and a four-extremity electrodiagnostic study (EMG/NCS). Class I limbs have no history of remote or recent weakness, normal strength, and a normal EMG. Class II limbs have no history of remote or recent weakness (or if remote history of weakness, full recovery occurred), normal strength and EMG evidence of prior anterior horn cell disease (AHCD). Class III limbs have a history of remote weakness with variable recovery, no new weakness, decreased strength, and EMG evidence of prior AHCD. Class IV limbs have a history of remote weakness with variable recovery, new clinical weakness, decreased strength, and EMG evidence of AHCD. Class V limbs have a history of severe weakness with little-to-no recovery, severely decreased strength and atrophy, and few-to-no motor units on EMG. In a prospective study of 400 limbs in 100 consecutive post-polio patients attending our clinic, 94 (23%) limbs were Class I, 88 (22%) were Class II, 95 (24%) were Class III, 75 (19%) were Class IV, and 48 (12%) were Class V. Guidelines for the use of this classification in a clinical/research setting are presented along with sample case histories and class-specific exercise recommendations.

Note: An Appendix with a Summary of Each Class and Proposed Exercise/Activities follows the list of References.

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APPENDIX

Summary of Each Class and Proposed Exercise/Activities.

Class I. No Clinical Polio.

Remote history	No weakness.
Recent history	No new weakness.
Physical exam	Good-to-normal strength. Normal sensation and reflexes. No atrophy.
EMG/NCS	Normal (using standard screening exam).

Recommended Exercises.

- Moderate intensity for nonathletic adults (using guidelines of the American College of Sports Medicine).
- Intensity: 60-80% of maximal heart rate or 6-9 metabolic equivalents (mets).
- Duration: 15-30 min.
- Frequency: 3-5 days a week.
- Sample exercises
  - Swimming 25-35 yards/min.
  - Walking 5-6 mph.
  - Bicycle riding 12-14 mph.

Class II. Subclinical Polio

Remote history	No weakness or if affected, full clinical recovery.
Recent history	No new weakness.
Physical exam	Good-to-normal strength. Normal sensation and reflexes. No atrophy.
EMG/NCS	Chronic denervation consistent with anterior horn cell disease (large polyphasic motor unit action potentials). No evidence of acute denervation.

Proposed Exercises.

- Modify Class I.
- Intensity: 60-80% reserve heart rate or 5-7 mets.
- Duration: 15-30 min.
- Frequency: 3-4 days/week on alternate days.
- Pacing: Perform 4-5 min, rest 1 min.
- Sample exercises
    - Swimming 25 yards/min.
    - Walking 4-5 mph.
    - Bicycle riding 10-12 mph.

N.B. Decrease if pain, fatigue or new weakness.

Class III. Clinically Stable Polio.

Remote history	Weakness with variable recovery.
Recent history	No new weakness.
Physical exam	Poor-to-good strength. Normal sensation. Normal-to-decreased reflexes May have atrophy.
EMG/NCS	Chronic denervation consistent with anterior horn cell disease. May have evidence of acute denervation.

Proposed Exercises.

- Intensity: 4-5 mets.

- Duration: 15-20 min.
- Frequency: 3-4 times/week on alternate days.
- Pacing: Resting 1 min/2-3 min of activity.
- Sample activities
    - Swimming 20 yards/min.
    - Walking 4 mph.
    - Bicycle riding 10 mph.

N.B. Modify if new weakness, pain or fatigue.

Class IV. Clinically Unstable Polio.

Remote history	Weakness with variable recovery.
Recent history	New weakness.
Physical exam	Poor-to-good strength. Normal sensation. Normal-to-decreased reflexes. May have atrophy.
EMG/NCS	Chronic denervation. May have evidence of acute denervation.

Proposed Exercises.

- Trial of rest to exclude overuse.
- Daily active/passive stretching program.
- Aerobic exercises in activities of daily living.
- No cardiopulmonary aerobic exercise.
- If overuse excluded, trial of monitored, nonfatiguing progressive resistive exercise program.
- If overuse weakness, modify activity, use bracing, scooter, etc.

Class V. Severely Atrophic Polio.

Remote history	Weakness with little recovery.
Recent history	May have new weakness.
Physical exam	Trace-to-poor strength. Normal sensation. Areflexic. Severe atrophy.
EMG/NCS	Decreased insertional activity. Few-to-no motor unit action potentials of variable size. May have acute denervation.

Proposed Exercises.

- Performing activities of daily living.
- Bracing and/or wheelchair usually needed.

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