Findings in Post-Poliomyelitis Syndrome

Weakness of Muscles of the Calf as a Source of Late Pain and Fatigue of Muscles of the Thigh after Poliomyelitis*

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ABSTRACT: The purpose of this study was to identify overuse of muscles and other alterations in the mechanics of gait in twenty-one patients who had muscular dysfunction as a late consequence of poliomyelitis. All of the patients had good or normal strength (grade 4 or 5) of the vastus lateralis and zero to fair strength (grade 0 to 3) of the calf, as determined by manual testing.

Dynamic electromyography was used, while the patients were walking, to quantify the intensity and duration of contraction of the inferior part of the gluteus maximus, the long head of the biceps femoris. the vastus lateralis, and the soleus muscles. Patterns of contact of the foot with the floor, temporal-spatial parameters, and motion of the knee and ankle were recorded.

The principal mechanisms of substitution for a weak calf muscle fell into three groups: overuse of the quadriceps (twelve patients) or a hip extensor (the inferior part of the gluteus maximus in eight patients and the long head of the biceps femoris in four), or both; equinus contracture (twelve patients); and avoidance of loading-response flexion of the knee (five patients). Most patients used more than one method of substitution.

These obervations support the theory that postpoliomyelitis syndrome results from long-term substitutions for muscular weakness that place increased demands on joints, ligaments, and muscles and that treatment -- based on the early identification of overuse of muscles and ligamentous strain -- should aim at modification of lifestyle and include use of a brace.

After thirty years or more of good function after recovery from acute poliomyelitis, survivors now are experiencing new weakness, fatigue, and pain*[11,12,21]*. At the end of an active day, the muscles of the thigh often ache and may cramp at night. Anatomical *[14]*, clinical*[1,4]*, and electromyographic investigations*[23,24]* have implicated overuse as the source of post-poliomyelitis symptoms.

It is well known that the quadriceps stabilizes the knee as the limb is loaded: less recognized is the action of the muscles of the calf particularly the soleus in providing indirect stability of the knee as body weight advances over a restrained tibia[20]. This action allows the quadriceps to relax. When the calf muscles lack the strength to provide tibial stability, the quadriceps must continue to support the knee actively and overuse can occur.

We found that susceptibility to overuse may not be obvious in a patient in whom manual tests show grade-4 or 5 muscle strength and who seems to move normally; there may be no conspicuous indication of any weakness of the calf muscles because of subtle substitution and a mild contracture. We therefore performed a dynamic electromyographic study of gait in patients who had post-poliomyelitis syndrome, weak calf muscles, and good quadriceps strength.

Materials and Methods

Patients who attended the Polio Clinic of Rancho Los Amigos Medical Center were referred to the Pathokinesiology Laboratory for instrumented gait analysis when dynamic electromyography was indicated to clarify the pattern of muscular activity during walking, for the planning of treatment or substantiation of a disability claim. Patients were included in this study if the strength on manual muscle-testing of the vastus lateralis was good (grade 4) or normal (grade 5) and that of the soleus was zero to fair (grades 0 to 3). The study group comprised twenty-one patients (eleven women and ten men). The mean age (and one standard deviation) was 50 ± 11 years, and the mean interval after the onset of the acute poliomyelitis was 39 ± 8 years. All of the patients had symptoms characteristic of post-poliomyelitis syndrome -- that is, pain, fatigue, and increasing weakness in the muscles of the calf or thigh.

Four weight-bearing muscles were studied: two hip extensors (the gluteus maximus and the long head of the biceps femoris), one component of the quadriceps (the vastus lateralis), and the major plantar flexor of the ankle (the soleus). Muscle strength was measured with both manual testing and a static dynamometer (Cybex II; Lumex, Bay Shore, New York). Activity of the muscles was recorded with intramuscular dynamic electromyography while the patients walked at their customary (free) speed. A pair of fine-wire electrodes (fifty micrometers in diameter with a two-millimeter bared tip) was inserted, with a single needle used as a cannula, into the belly of each designated muscle. The accuracy of the placement of the electrodes was confirmed with light electrical stimulation.

The bandwidth of the electromyographic recording was 150 to 1000 hertz. The electromyogram of each muscle was sampled 2500 times per second, rectified full-wave, and integrated for each 1 per cent of the gait cycle. The electromyographic values during gait were normalized to the levels of the electromyogram that had been recorded during manual testing, The total effort of the individual muscles was calculated as the product of intensity and duration. These values were compared with similar data from normal controls who were twenty to twenty-five years old. The soleus was tested in fourteen normal controls; the vastus lateralis, in twenty-eight; the biceps fcmoris, in twenty-eight; and the inferior part of the gluteus maximus, in twenty-five. Overuse or underuse of the muscle was designated if the activity differed from the normal mean by more than two standard deviations.

Motion of the knee and ankle joints was determined with the use of single-axis goniometers. The parallelogram construction and slight rotatory-axis mobility of the goniometers accommodated for minor deviations in the alignment of the joint center. The stride characteristics were recorded by a Footswitch Stride Analyzer (B and L Engineering, Santa Fe Springs, California). All data regarding gait were collected as the patients walked along a vinyl-tiled, ten-meter-long walkway. Photoelectric cells defined the middle six meters as the segment for the collection of data.

Results

Manual testing confirmed that all of the patients who had post-poliomyelitis syndrome had grade-4 or 5 strength of the vastus lateralis (Table I). Quantified torque-testing showed that grade 5 indicated 59 ± 19.8 per cent (mean and standard deviation) (range, 41 to 77 per cent) of normal strength and grade 4 indicated 41 ± 20.2 per cent (range, 17 to 67 per cent) of normal strength. Hence, all of the patients had substantial weakness of the vastus literalis.

TABLE I
Muscle Strength*

Muscle	Grade on Manual Muscle-Testing[15,16]**	No. of Patients	Percentage of Normal Torque***
Vastus lateralis			
	5	2	59 ± 19.8
	4	19	41 ± 20.2
	3	0	
	2	0	
	0	0	
Soleus			
	5	0	
	4	0	
	3	8	25 ± 13.3
	2	10	17 ± 12.6
	0	1	7
Inferior part of the gluteus maximus			
	5	1	78
	4	9	55 ± 13.3
	3	10	32 ± 10.6
	2	0	
	0	0	
Long head of the biceps femoris			
	5	1	78

	4	11	42 ± 21.6
	3	5	41 ± 15.6
	2	1	26
	0	0	

*The strength of the vastus lateralis was tested in twenty-one patients; that of the soleus, in nineteen; that of the inferior part of the gluteus maximus, in twenty; and that of the long head of the biceps femoris, in eighteen.
**Grade 5 indicates normal muscle strength; grade 4, good muscle strength; grade 3, fair muscle strength; grade 2, poor muscle strength; and grade 0, no muscle strength.
***The values are given as the mean and the standard deviation.

The findings for the hip extensors were similar. The strength of the inferior part of the gluteus maximus was tested in twenty patients, and the strength of the long head of the biceps femoris was tested in eighteen. On manual muscle-testing, the mean grade for both the inferior part of the gluteus maximus and the long head of the biceps femoris was 4, although individual strengths ranged from grade 2 to grade 5 (Table I). The mean strength of the hip extensors was 44 ± 20 per cent (range, 17 to 84 per cent) of normal. Quantified torque was not recorded when the muscle could not produce an active contraction or electromyographic activity could not be elicited.

Of the nineteen patients for whom it was tested, eight had grade-3 strength of the soleus muscle; ten grade-2; and one, grade-0 (Table I). The mean quantified strength of the grade-3 muscles was 25 ± 13.3 per cent (range, 17 to 51 per cent) of normal, and that of the grade-2 muscles was 17 ± 12.6 per cent (range, 4 to 37 per cent).

Overuse during walking (a total effort of more than two standard deviations more than normal) was found in all four muscle groups. Overuse was most common in the quadriceps, but it also was frequent in the inferior part of the gluteus maximus (Tables II and III). Overuse was less common in the long head of the biceps femoris and was infrequent among the weak soleus muscles.

TABLE II
Electromyographic Pattern of Muscle Use

	Total Effort		
Muscle	Normal Controls*	Muscles Showing Overuse*	Percentage of Normal**
Vastus lateralis	414 ± 218	2148 ± 1370 (n=12)	519
Soleus	1719 ± 594	4707 ± 594 (n=3)	274
Inferior part of the gluteus maximus	242 ± 140	1316 ± 705 (n=8)	544
Long head of the biceps femoris	399 ± 357	1692 ± 370	424

		(n=4)	

*The total effort was the intensity (the percentage of the manual-muscle-test level) multiplied by the duration (the percentage of the gait cycle). The values are given as the mean and the standard deviation.
**For the muscles showing overuse.

The quadriceps displayed three patterns of effort: overuse, normal, and underuse. Overuse was identified in twelve of the twenty-one patients (Table III). Both the intensity and the duration of activity exceeded the normal mean by more than two standard deviations. A flexion contracture of the knee was found in five patients, four of whom displayed overuse of the quadriceps.

Normal function of the quadriceps was seen in seven patients (Table III). Four of these seven showed overuse of the inferior part of the gluteus maximus or the biceps femoris, or both. In the six patients in whom the soleus was also tested, two demonstrated overuse of that muscle.

Underuse of the quadriceps was seen in two patients (Table III), and overuse of the inferior part of the gluteus maximus (which we assumed was compensatory) was found in one of them. A related gait pattern was loading-response extension of the knee r eplacing normal flexion. This was exhibited by five patients; all had evidence of underuse of the quadriceps but the activity of the muscle differed from the normal mean by more than two standard deviations in only two.

Ten of the twenty-one patients had overuse of the hip extensors. Eight of the twenty gluteus maximus muscles tested showed overuse as prolonged duration, and four of the seventeen biceps femoris muscles tested showed overuse as increased intensity and duration. (Both extensors were not tested in every patient.)

The effort of the soleus was within two standard deviations of the normal mean in twelve of the nineteen patients in whom it was tested. Three patients had overuse and four had underuse. Related to this pattern of function was the relatively frequent occurrence of an equinus contracture, which was present in twelve of the twenty-one patients in the study. Only one of these twelve exhibited overuse of the soleus, seven had normal function, two had und eruse, and the soleus was not tested in two because of the absence of function. The maximum passive dorsiflexion of the ankle in eleven of these twelve patients ranged from 0 to -15 degrees. The remaining patient had a severe contracture with maximum passive dorsiflexion to -35 degrees; the ankle remained in -35 degrees of dorsiflexion. Most of the contractures stretched at least partially from the effect of body weight during walking; nine of the twelve patients had substantial dorsiflexion of the ankle (mean, 7 degrees) in terminal stance. Two patients maintained slight equinus (-3 degrees of dorsiflexion) in terminal stance. For the nine patients who did not have an equinus contracture, maximum passive dorsifexion of the ankle ranged from 5 to 10 degrees, and dorsiflexion of the ankle in terminal stance averaged 12 degrees. A linear correlation ($r=0.47$, $p < 0.03$) was found between the intensity of maximum activity of the quadriceps, as recorded electromyographically, and the magnitude of dorsiflexion of the ankle in terminal stance (-15 to 10 degrees). The patient who had a severe equinus contracture (35 degrees) was excluded from the correlation.

TABLE III

Electromyographic Patterns of Muscle Use*

Case	Vastus Lateralis	Soleus	Inferior Part of the Gluteus Maximus	Long Head of the Biceps Femoris
1	Overuse	Normal	Overuse	Normal
2	Overuse	Normal	Overuse	Normal
3	Overuse	Normal	Overuse	Normal
4	Overuse	Normal	Overuse	Normal
5	Overuse	Normal	Overuse	Overuse
6	Overuse	Overuse	Underuse	Normal
7	Overuse	Not Tested	Normal	Not Tested
8	Overuse	Normal	Not Tested	No rm al
9	Overuse	Normal	Normal	Normal
10	Overuse	Normal	Underuse	Normal
11	Overuse	Underuse	Normal	Underuse
12	Overuse	Underuse	Normal	Not Tested
13	Normal	Normal	Overuse	Normal
14	Normal	Normal	Normal	Overuse
15	Normal	Underuse	Normal	Overuse
16	Normal	Overuse	Overuse	Overuse
17	Normal	Overuse	Normal	Normal
18	Normal	Not Tested	Normal	Normal
19	Normal	Underuse	Normal	Normal
20	Underuse	Normal	Normal	Not Tested
21	Underuse	Normal	Overuse	Not Tested

*Overuse and underuse were considered to differ from the normal mean by more than two standard deviations.

Discussion

Weakness is the basic abnormality of the post-poliomyelitis syndrome. Bodian, in a study of acute poliomyelitis, found that the virus had invaded 95 per cent of the anterior horn cells within the nervous system and that, on the average, 47 per cent (range, 12 to 91 per cent) recovered. Other studies showed that additional function was regained through the adoption of denervated muscle fibers by axons that sprout[28,29] and by compensatory hypertrophy of partially denervated muscles[8-10]. By these mechanisms, most survivors of acute poliomyelitis regained the ability to walk in an apparently normal manner and to have an active lifestyle. The neuromuscular system being used, however, has a sub-normal number of motor units and enlarged muscle-fiber pools[27]. As a result, these patients had a limited tolerance for chronic strain. Now, more than thirty years after the acute disease, many survivors have symptoms of new weakness, fatigue, and pain[11,12,21].

It is a clinical challenge to identify the specific residual weakness in a patient who has a very efficient substitution system. When patients who have had poliomyelitis have normal motor control and normal proprioception, they can readily and subtly modify muscular activity to compensate for areas of dysfunction[19]. For example, they can compensate for weak calf muscles when walking.

Weakness of the muscles of the calf, and the limited ability of a so-called good quadriceps to compensate, are rarely appreciated in patients who have had poliomyelitis because the signs of impairment are subtle. Although Beasley demonstrated, more than thirty years ago, that an examiner using manual testing cannot sense the full strength of large muscles such as the quadriceps, grade 5 continues to be interpreted as representing normal function. Beasley found that strength rated grade 5 on the basis of manual testing in patients who had had poliomyelitis was equivalent to 53 per cent of the strength in normal controls. In the present study, grade-5 strength of the quadriceps muscle in patients who had had poliomyelitis was equivalent, on the average, to only 59 per cent of the strength in normal controls. Grade-4 strength also tends to be considered to be closer to normal than it is. Both the study by Beasley and the present study showed that the mean strength of the grade-4 muscles w as approximately 40 per cent of normal (in the present study, the quadriceps was 41 per cent of normal and the hip extensors, 44 per cent of normal). Muscles with grade-5, 4, or even 3+ strength allow a person to move normally; the greater intensity of effort is unrecognized. When clinical treatment is being planned, the strength of a quadriceps that was given a grade of 4 or 5 on manual testing should be quantified more precisely with a static dynamometer such as a Cybex II device.

An additional diagnostic complication is the difficulty involved in the determination of the strength of the plantar flexors of the ankle. Manual testing challenges only 20 per cent of normal strength[3,18]. The forefoot is not long enough to give the examiner sufficient leverage to simulate the demand that the weight of the body places on these muscles with each stride. Multiple heel-rises have been used as a basis for grading, but the standard number of heel-rises has ranged from one[3] to ten[13]. Recent research has revealed that the mean normal endurance is twenty[18].

Walking presents a rapid demand on the quadriceps to control a passively flexed knee during weight-acceptance in stance. The prompt response of the four parts of the quadriccps generates a peak intensity (25 per cent of maximum effort as evidenced by manual muscle-testing) within the first 5 per cent of the gait cycle[20]. Once the forefoot contacts the ground and the mechanics of knee flexion have subsided, the activity of the quadriceps is reduced until it becomes silent by the 20 per cent point in the gait cycle. This is a non-fatiguing level of activity for normal muscles and thus can be repeated indefinitely[17]. A grade-5 quadriceps with strength that is 59 per cent of normal must create a peak inten sity of 42 per cent of the manual-muscle-test level to control the flexing knee. When the strength of the quadriceps is grade 4, the peak effort during the weight-acceptance period of each stride represents 60 per cent of the capability of the muscle. The anaerobic stage of contraction has been entered[2], and endurance is substantially reduced. This disability is masked by the patient's ability to move in a normal manner by increasing the intensity of effort to a point of overuse[22].

The muscles of the calf (the soleus and gastrocnemius) make a major contribution to the stability of the knee during the period of single-limb stance. As the weight of the body is drawn forward over the supporting foot by the momentum of the swinging limb, the soleus and gastrocnemius create a force of plantar flexion of the ankle to decelerate the rate of tibial advancement[20]. This provides passive stabi lity of the knee as soon as the body-weight line (vector) moves anterior to the knee (mid-stance). The knee progressively extends as the limb advances, but quadriceps action is not needed. The normal pattern of action of the muscles of the calf is one of high intensity and prolonged duration. Soleus action begins in the latter part of the loading response (the 5 per cent point in the gait cycle) and continues throughout terminal stance for a total period of activity equaling 45 per cent of the gait cycle. The intensity of soleus action increases rapidly to 30 per cent of the manual-muscle-test level through mid-stance as the limb advances over the flat foot and then progressively increases after heel-rise to a peak intensity of 80 per cent of the manual-muscle-test level during terminal stance. The action of the gastrocnemius is similar.

Weakness of the muscles of the calf allows the tibia to fall anteriorly in an unconstrained manner, and the opportunity to stabilize the tibia passively is lost[25]. Flexion of the knee persists throughout stance[26], and continued quadriceps action is required to preserve weight-bearing stability[20]. This is the basis of the increased duration of activity that results in overuse of the quadriceps.

The signs of late weakness of the muscles of the calf in a person who has had poliomyelitis are subtle. An inability to accomplish twenty full-range heel-rises on one side is an indication of muscular weakness. Fewer heel-rises indicate an even greater loss of strength. When a patient is walking, persistent heel contact during the second half of the single-stance period (terminal stance) is a basic indication of weakness. The patient lacks the strength to support the weight of the body on the fore-foot before the other foot strikes the ground. Increased dorsiflexion of the ankle becomes visible. The length of the stride is shortened. Flexion of the knee in mid-stance and terminal stance occurs when weakness of the soleus is more marked. Avoidance of loading-response flexion of the knee and sustained contraction of the quadriceps is an alternate mechanism of substitution.

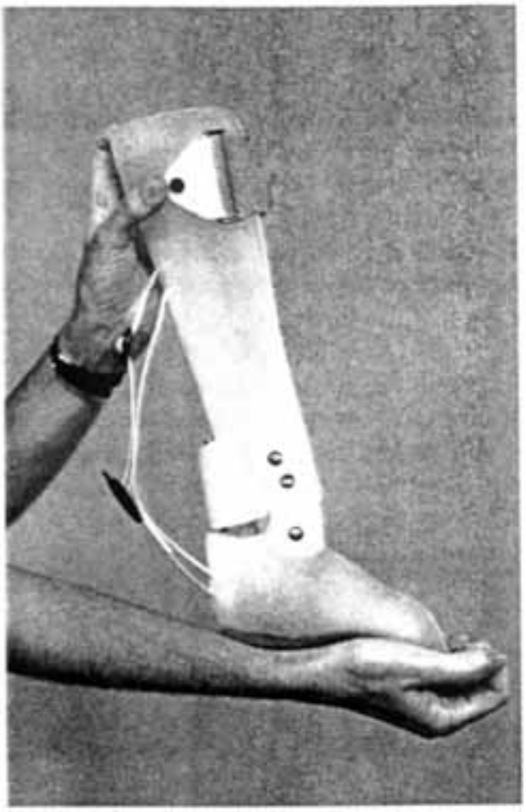

Figure 1. Photograph of an ankle-foot orthosis with a hinged ankle joint, showing free plantar flexion.

Contractures can have an adverse or beneficial influence on gait. A flexion contracture of the knee prevents the knee from reaching the stable position of passive extension. As a result, persistent quadriceps activity is required throughout the weight-bearing phase of gait, and either an early heel-rise or greater dorsiflexion of the ankle is required. In contrast, an equinus contracture of the ankle can be a useful substitute for weak calf muscles. Tension of the fibrous-tissue elements within the soleus and gastrocnemius provides the tibial restraint needed for indirect stabilization of the knee. The demand on the quadriceps is proportionately reduced.

Overuse of the hip extensors represents a substitutive effort to reduce the demand on the quadriceps. The action of the hip extensors is increased to support the anterior lean of the trunk. This posture moves the body vector closer, or even anterior, to the center of the knee joint. The flexor moment at the knee is correspond ingly shortened, and less quadriceps force is required[5]. Each of the hip extcnsors has a direct effect at the knee as well. The gluteus maximus, through its insertion into the iliotibial band, can produce extension of the knee directly. When the knee is flexed less than 30 degrees, the tibial insertion of the band lies anterior to the axis of the knee joint and thus is an extensor. In contrast, the tendon of the biceps femoris, by inserting on the head of the fibula, is consistently aligned to induce flexion of the knee. As a result, the anterior posture of the trunk, being supported by the hamstring muscle group, also creates slight flexion of the knee. The differing effects at the knee most likely account for the more frequent overuse of the gluteus maximus.

The most expedient way to reduce symptoms in the thigh caused by overuse of the quadriceps and hamstring muscles is use of an ankle-foot orthosis that supplants the weak calf muscles[7] and also protects the quadriceps. As the orthosis has two critical functions, a simple solid shell is inappropriate. In normal gait, a small but essential arc of 10 degrees of plantar flexion of the ankle follows heel-strike. This loading-response reduces the tibial acceleration of the heel lever[20]. As a result, flexion of the knee lags behind the rate of foot-drop, and the potential demand on the quadriceps is reduced approximately 50 per cent. Freedom of plantar flexion of 15 or 20 degrees also allows a patient who has had poliomyelitis to attain flat-foot contact with the floor while the knee is fully extended. Thus, all demand for use of the quadriceps can be avoided. During late mid-stance and terminal stance, tibial restraint must be provided by a dorsiflexion stop. Eleven of our twenty-one patients wore a hinged ankle-foot orthosis with a dorsiflexion stop. Nine of them reported subjective relief of symptoms, o ne was un sure if there had been any improvement, and one was lost to follow-up.

The appropriate orthosis for a patient who has weakness of the muscles of the calf and quadriceps strength that is less than truly normal (even though it may appear normal on manual testing) must have three qualities; it must be articulated (hinged); it must allow free plantar ncxion of 15 or 20 degrees (Fig. 1); and it must have an adjustable dorsiflexion stop to restrain the tibia (Fig. 2). The mean setting to restrain excessive tibial advancement is 5 degrees of dorsiflexion; stronger patients, who are capable of longer strides, prefer 10 degrees of dorsiflexion. Rarely is 0 degrees of dorsiflexion or a plantar-flexed setting appropriate because these inhibit advancement of the weight of the body over the forefoot and induce a hyperextension thrust on the knee.

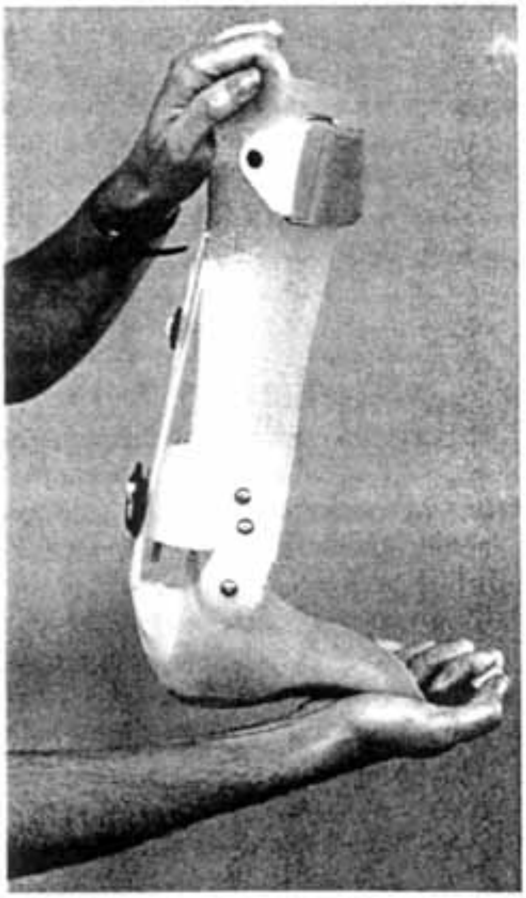

Figure 2. Photograph of an ankle-foot orthosis with a dorsiflexion stop, showing limited dorsiflexion.

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