Change in Lower Limb Isokinetic Muscle Strength of Polio Survivors over 5-Year Follow-up

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Abstract: To evaluate the muscle strength of the lower limbs over time in polio survivors during 5 years of follow-up and to examine the rate of change in their muscle strength, we performed a prospective, longitudinal study of polio survivors (n = 63: 61 with postpolio syndrome) living in the community who participated voluntarily. Their isokinetic knee-extensor and knee-flexor muscle strength (peak torque) at angular velocities of 60 and 120 deg/sec, using a fixed dynamometer (Biodex) were measured over a 5-year period. At 5-year follow-up, approximately 90% of the subjects had decreased knee extensor strength at both angular velocity of 60 and 120 deg/sec: similarly, at both angular velocities, approximately 80% of the subjects had decreased knee flexor strength. The annual average rate of decrease in the peak torque of the knee extenders was significantly greater than that of the flexors at both angular velocities, and the difference in the rates between the extenders and the flexors was marked at the faster angular velocity. The polio survivors had a progressive decrease in lower limb isokinetic muscle strength over time. In addition, the annual rate of decrease of the knee-extensor, the so-called weight bearing muscle, was greater than that of the knee-flexor.

Key words: muscle strength, isokinetic force, polio, rehabilitation.

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Introduction

Post-polio syndrome (PPS) is generally defined as a clinical syndrome of new muscle weakness, fatigue, and pain in individuals who have previously recovered from acute paralytic poliomyelitis [1, 2]. In recent years, PPS has become a serious issue for Japanese polio survivors, and it appears that Japan is following approximately 10 years or more behind the USA. We performed an epidemiological survey of PPS in an area with one million inhabi-
tants in Japan and found that the prevalence of PPS was 18.0 per 100,000 population [3]. We also found that progressive muscle weakness had limited their daily and social activities [4].

The muscle strength of polio survivors generally decreases over time [1, 5–12], and reduction of muscle strength has been thought to be greater than that which occurs with normal aging. One of the proposed mechanisms for progressive muscle weakness in PPS is distal degeneration of massively enlarged motor units from axonal sprouting after acute paralytic poliomyelitis. However, there have been contradictory reports that patients with PPS had increased [13, 14] or constant [15–17] muscle strength. The reason for the above contradictory results is mainly methodological differences between studies, such as subjects’ criteria, measurement of muscle strength, and follow-up periods. In particular, manual muscle testing (MMT) [1, 12, 14, 15] and the hand-held dynamometer (HHD) [9, 12, 14] are limited in detecting changes in muscle strength, and their interexaminer reliabilities are poor [18, 19]. Furthermore, deterioration in muscle strength cannot be detected in a short follow-up period of less than 2 years [19]. Therefore, quantitative muscle strength testing using a fixed dynamometer and a long-term follow-up period of at least 4 years are needed to study the muscle strength of polio survivors.

The purpose of the present study was: 1) to evaluate the lower extremity muscle strength using a reliable measurement method, the fixed dynamometer, in polio survivors over a 5-year period; and 2) to examine the rate of change in their knee-extensor and knee-flexor muscle strength.

Methods

Subjects

The subjects were recruited from the support group for polio survivors living in the North-Kyushu area of Japan (population of one million), where approximately 340 polio survivors were identified [3]. A total of 110 polio survivors voluntarily participated in the annual health examination for PPS and visited our hospital between 2001 and 2006. They were part of the polio survivors’ population that we had previously surveyed. Inclusion criteria for the present study were: 1) a history of previous polio that was confirmed by the subjects’ physically disabled persons’ certificates; and 2) physical examination consistent with past paralytic polio. Most of the polio survivors with paralysis had physically disabled persons’ certificates that had been issued based on the law for the Welfare of Physically Disabled Persons in Japan.

Study design

Subjects were evaluated prospectively over a 5-year period between 2001 and 2006. Data for this study were obtained at the time of presentation to our hospital. The outcome vari-
able was isokinetic muscle strength of the lower limbs, which was obtained using an isokinetic strength dynamometer (described in the next section). Data on the following variables were also obtained by interview and examination: age, sex, age at the time of acute polio, general muscle weakness evaluated by MMT of the four extremities, personal activities evaluated using the Barthel ADL index (BI) [20], and instrumental activities evaluated using the Frenchay Activities Index (FAI) [21] at the time of presentation. An MMT sum score, ranging between 0 and 110, was obtained by adding the values of all 11 muscle groups bilaterally: shoulder flexion, elbow flexion and extension, wrist extension, finger abduction, hip flexion and extension, knee flexion and extension, and ankle dorsiflexion and plantarflexion. The details of the BI and FAI scales that evaluate mobility-related activities have been described previously [22]. Each subject was followed up every year at the annual health examination for polio survivors in the study area, and isokinetic muscle strength testing was repeated (Fig. 1).

**Isokinetic muscle strength testing**

Isokinetic muscle strength of the lower limbs was measured in subjects whose MMT scores for both knee-extension and knee-flexion were 4 or 5. This allowed subjects with mildly affected lower limbs to be included in the study (Fig.1).

We used the Biodex® System 3 Isokinetic Dynamometer to measure isokinetic knee-extension and knee-flexion strength at angular velocities of 60 and 120 deg/sec. The subject was positioned according to the standard knee testing procedures outlined in the Biodex System 3 Operations Manual. At each angular velocity, the subject performed 3 trial repetitions prior to the actual test to become familiar with the procedure. Following the trial repetitions, the subject performed 5 repetitions of maximal knee extension and flexion isokinetic contractions. While performing knee extension and flexion, the subject was verbally directed with the words "kick" and "bend", respectively. The highest torque values for each subject were recorded as the peak torque (PT) for subsequent analyses.

**Statistical analysis**

The JMP®7 (SAS Institute Inc) statistical analysis program was used to obtain descriptive statistics and perform univariate and survival analyses. First, we evaluated the proportion of subjects with decreased PT during follow-up, using the method of survival analysis, i.e. the time-to-failure or Kaplan-Meier analysis. This analysis takes different follow-up periods in each case into consideration. Second, secular change of the PT values was analyzed using ANOVA. Finally, each percent change of the PT values in the two directions at the two angular velocities was calculated from the PT values at baseline (PTbase), at the last visit (PTlast), and at the follow-up years (Y) during the study according to the formula: % change of PT per year = (PTlast−PTbase)×100 / (PTbase×Y) (%). Student t-test was used to compare the percent change of the PT values between the two directions.
Results

Some of the study subjects' characteristics are presented in the Table 1. A total of 63 subjects (27 men and 36 women) with 76 affected lower limbs completed the requirements at the baseline of the study. Their mean age was 54.5 years, and 57% were women. The mean age at the time of acute polio onset was 2.3 years. Ninety-seven percent of the subjects (61 subjects) met Halstead's criteria of PPS [23]: 1) a history and physical examination compatible with paralytic polio; 2) at least 15 years of functional stability following initial recovery; 3) new symptoms of increased or new muscular weakness, and fatigue (muscular and/or general); and 4) no other neurological or medical conditions that could produce weakness and fatigue. Most of the subjects had a normal weight (mean body mass index score, 22.8). Forty percent of the subjects were using either a knee-ankle-foot orthosis or an ankle-foot orthosis. They were independent in personal and instrumental activities (mean total BI 98.4,
The characteristics of the present sample were similar to those of our original population [3].

Figure 2 shows the proportion of subjects with decreased isokinetic muscle strength at follow-up, taking into consideration cases who were lost to follow-up or had different lengths of follow-up. At the final follow-up, approximately 90% of the subjects had decreased knee extension strength at both angular velocities (60 and 120 deg/sec). Similarly, approximately 80% of the subjects had decreased knee flexion strength at both angular velocities.

Figure 3 shows the secular changes of the values of isokinetic muscle strength measured as PT of knee extension and flexion at angular velocities of 60 and 120 deg/sec. At both speeds and in both directions, the PT values were almost constant during the first three years, and then reduced. However, this trend was not statistically significant on ANOVA, probably due to the number of lost-to-follow-up cases.

The annual average rate of decrease in the PT (% change of PT) is shown in Fig 4. At an angular velocity of 60 deg/sec, the rate of decrease in knee extension (7.8%) was greater than that of knee flexion (5.1%) (Fig. 4, left). Similarly, at an angular velocity of 120 deg/sec, the rate of decrease in knee extension (8.8%) was significantly greater than that in knee flexion (1.6%) (Fig. 4, right).

Table 1. Subjects’ characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Number (%)</th>
<th>Mean (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yrs</td>
<td>54.50 (8.12)</td>
<td>41 - 76</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>27 (42.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>36 (57.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age at polio onset, yrs</td>
<td>2.28 (3.69)</td>
<td>0.25 - 28.0</td>
<td></td>
</tr>
<tr>
<td>Body height, cm</td>
<td>155.68 (8.62)</td>
<td>134.6 - 177.0</td>
<td></td>
</tr>
<tr>
<td>Body weight, kg</td>
<td>55.75 (12.19)</td>
<td>30.4 - 83.6</td>
<td></td>
</tr>
<tr>
<td>Body Mass Index, kg/m²</td>
<td>22.82 (3.68)</td>
<td>15.76 - 30.76</td>
<td></td>
</tr>
<tr>
<td>Manual Muscle Test total</td>
<td>83.51 (14.51)</td>
<td>20.0 - 110.0</td>
<td></td>
</tr>
<tr>
<td>Braces</td>
<td>25* (39.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee-ankle-foot orthosis</td>
<td>12 (19.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle-foot orthosis</td>
<td>14 (22.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barthel ADL index</td>
<td>98.42 (4.66)</td>
<td>71 - 100</td>
<td></td>
</tr>
<tr>
<td>Frenchay Activities Index</td>
<td>26.35 (9.00)</td>
<td>2.0 - 42.0</td>
<td></td>
</tr>
</tbody>
</table>

SD: standard deviation, *: One case used left knee-ankle-foot orthosis and right ankle-foot orthosis. N=63
Fig. 2. Proportion of the subjects with progressing muscle weakness in Kaplan-Meier method. PT: peak torque, KE: knee extension, KF: knee flexion.

Fig. 3. Deterioration of isokinetic muscle strength during the study.

- : knee extension (60), ○ : knee flexion (60),
- ▲ : knee extension (120), ▲ : knee flexion (120 deg/sec).
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**Fig. 4.** Percent change of peak torque per year isokinetic muscle strength. KE: knee extension, KF: knee flexion, Mean ± SE, *: P < 0.01.

**Discussion**

This study design was unique and reliable in that quantitative muscle strength testing was performed using the fixed dynamometer (Biodex) rather than the MMT evaluation, and the follow-up was long (5 years), according to the recommendations of Stolwijk-Swüste *et al.* [19]. Because of the subjectivity of the MMT, dynamometry was used to provide objective data to establish muscle strength exactly.

The results of the present study were compared to the studies using fixed dynamometers [5–8, 10, 11, 13, 17, 24]. Many such studies reported decreased muscle strength over time, while one study by *Munin et al.* [13] reported increased muscle strength; 7 PPS patients who were followed-up for 3 years had increased isokinetic muscle strength, from 15% to 36%. Their results appear to have been overestimated because of the small number of cases, some missing values, and the short duration of follow-up. Considering the overlapping sample, the studies reporting reduced muscle strength using the fixed dynamometer were collected into two groups: Agre’s [8, 10, 17] and Grimby’s [5–7, 11, 24].

The results of the present 5-year follow-up study indicate that this sample population consisted of mostly post-polio patients who had progressive decreases in lower extremity isokinetic muscle strength (Fig. 3). In addition, the annual rate of decrease was greater for knee extension than for knee flexion. In particular, muscle strength was almost constant during the first three years, and then a gradual reduction was seen (Fig. 3). The results of the Kaplan-Meier analysis, which considered the cases lost to follow-up, showed an increasing...
proportion of subjects with reduced muscle strength over time (approximately 90% in knee extension and 80% in knee flexion at 5-years; see Fig 2). Muscular strength over a 4-year follow-up period clearly decreases 50 years after an episode of poliomyelitis. These results showing a reduction of muscle strength over time agreed with the studies by Agre [8, 10, 17] and Grimby [5-7, 11, 24], though the reduction rates were different. However, the average annual rates of decrease in the present study, 7.8% per year (60 deg/sec) and 8.8% per year (120 deg/sec) for knee extension, were greater than those of other studies. Agre et al. [10] reported an 8% reduction of isokinetic knee extensor strength over 4 years, while Grimby et al. [7] reported a 13% reduction at 60 deg/sec and a 15% reduction at 180 deg/sec over 8 years. The reason for the differences in the rates is mostly due to sample characteristics. The present sample was highly active, but older and included a higher proportion of PPS than Grimby's [7]. The initial muscle strength in the present sample was lower than that in Grimby's [7], which might have caused an overestimation of the rate of change even for a small absolute change over time. However, the present study, involving a larger sample, provided reliable data and consistent evidence that lower extremity muscle strength decreases over time in polio survivors.

The rate of lower extremity muscle deterioration was higher for knee extension than for knee flexion (Fig. 4). A previous study [9] reported that polio survivors developed deterioration of the knee flexors, not the knee extensors, because their braces compensated for the extensors in the stance phase, but the flexors in the swing phase were subject to repetitive stress for which the braces provided no compensation. However, the results of the study by Klein et al. [9] using HHD cannot be compared with the results of the present study using the fixed dynamometer. Furthermore, their sample was older than the present sample (mean age: 64 years vs. 54 years) and used braces more frequently (45 vs. 40%). We believe that deterioration in the strength of the knee extensor, the weight-bearing muscle, was more important for locomotion in polio survivors who were active.

The findings from the present study must be interpreted in light of the following limitations. First, since the majority of the subjects who were involved participated voluntarily, there could have been a selection bias. However, the sample would be representative of PPS patients in the area because the characteristics of the present sample were similar to those of our original population. Therefore, selection bias was thought to be minimal. Ninety-seven percent of the subjects were thought to have developed PPS, but cases with severe muscle weakness were excluded; thus, the findings in this study could be generalized only to survivors of mild to moderate polio. Second, the cases lost to follow-up during the observation period may have affected the results. Since this limitation might underestimate the association or reduce the statistical power, survival analysis that took each follow-up period into consideration was used, and the annual change of PT was calculated by averaging muscle strength during the observation period. Third, a fixed dynamometer was used for isokinetic muscle strength testing, which is more dynamic and changeable than isometric muscle
strength. Finally, the absence of age-matched controls without a history of poliomyelitis prevents examination of the cause of muscle weakness: normal aging or PPS. Delbaere et al. reported that the decline in muscle strength of the lower extremities was 40 to 47% during 20 years (2 to 3% per year) in middle-aged men using the Biodex [25]. Comparing this data of healthy subjects, and a larger decline rate in our subjects (8% per year) suggested that factors other than normal aging might influence the muscle weakness in polio survivors.

Despite these limitations, our findings demonstrate the consistency of the fact that polio survivors developed progressive muscle weakness that was greater than the usual rate of strength reduction over time. The present study used a reliable measurement method involving the dynamometer and a longer follow-up period. Further follow-up studies should be performed to clarify which intervention would be effective for improving or maintaining muscle strength.

Conclusions

The results of the present 5-year follow-up study demonstrate that this sample population, which consisted primarily of post-polio patients, had a progressive decrease in isokinetic lower extremity muscle strength. In addition, the annual rate of decrease was greater for the knee extensor, the weight-bearing muscle, than for the knee flexor.

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Muscle Strength of Polio Survivors

ポリオ罹患者における等運動性下肢筋力の5年間の変化

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要 旨： 5年間にわたるポリオ罹患者の下肢筋力の変化を評価するため、自主的に参加した地域在住のポリオ罹患者（63名、そのうち61名がポリオ後症候群）を対象として、前向き継続研究を実施した。すなわち、5年間にわたって毎年1回、固定式ダイナモーメーター（Biodex）を用いた等運動性膝伸展筋力および膝屈曲筋力（ピークトルク値）を60°/秒および120°/秒の角速度で測定した。5年後の時点で、対象者の約90%の者が両角速度での膝伸展筋力の低下を認め、同様に80%の対象者が膝屈曲筋力の低下を認めた。膝伸展筋力（ピークトルク値）の1年あたりの低下率は、両角速度において膝屈曲筋力のそれよりも有意に大きく、その差は角速度の速い場合により顕著であった。ポリオ罹患者の等運動性下肢筋力は、経年的に進行性低下をきたすこと。また、荷重である膝伸展筋力の低下率が膝屈曲筋力より大きいことが明らかとなった。

キーワード： 筋力、等運動性筋力、ポリオ、リハビリテーション。

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