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Gait Patterns in Spastic Hemiplegia in Children and Young Adults*

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NEWINGTON, CONNECTICUT
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ABSTRACT: Four homogeneous patterns of gait were defined in forty-six patients who had spastic hemiplegia secondary to cerebral palsy or other neurological disorders by analyzing kinematic data in the sagittal plane and electromyographic data. In Group I (twenty patients) the primary abnormality was a drop foot in the swing phase. The thirteen patients in Group II had a tight heel cord in the stance phase as well as a drop foot in the swing phase. The five patients in Group III also had more proximal involvement (that is, restricted motion of the knee) as well as an equinus deformity of the ankle. In Group IV, the eight patients had, in addition, restricted motion of the hip.

The term spastic hemiplegia is used for the neural deficit that may occur in patients who have a neurological disorder such as cerebral palsy, traumatic injury to the brain, or cerebrovascular accident. The word hemiplegia means the neuromuscular disorder that involves one-half of the body in the frontal plane while the other half is normal or near normal. Cerebral palsy is generally taken to mean a non-progressive disorder that begins either in utero or within the first two years of life, with a selective loss of muscle control. Many of the characteristics that are seen in patients who have cerebral palsy are similar to those in patients who have injury to the brain or a cerebrovascular accident in which the onset occurs later in life.

Surgery, bracing, or both, have been commonly used to improve the gait in patients who have spastic hemiplegia, but until recently the treatment was entirely empirical. Static muscle tests and observation of the patient's gait are done to determine which muscles are overactive and in need of lengthening. These tests, however, do not yield critical information from patients who have lesions of the brain because manual techniques for testing muscle depend on the patient's ability to selectively activate a particular muscle while simultaneously releasing the antagonist, and often patients who have the conditions that are under study are unable to coordinate these two muscular functions. Variables such as posture of the limbs, vestibular tone, patterns of locomotor coordination, and the rates at which muscles are stretched also may influence the findings. The result has been that variable regimens of treatment are prescribed for many patients who, from the clinical standpoint, appear to have similar involvement of the central nervous system. We decided to study whether more pertinent information could be obtained by use of new laboratory tests: dynamic electromyography and computerized measurements of the rotation of joints. These tests allow the physician to evaluate the function of the muscles and the position of the joints during gait and provide a more extensive and objective assessment of the neural deficit in patients who have spastic disorders.

In 1977, Bekey et al. classified the spastic gait of thirty patients into four categories using electromyographs of the muscles that activate motion of the foot and the ankle. They concluded that an accurate description of the various patterns of gait is possible if the patterns of movement of the entire lower extremity also were evaluated. In a follow-up study, Chang and Bekey discussed how they were able to apply recognition of patterns to the prediction of the changes in gait that could be expected postoperatively. Knutsson and Richards combined electromyographic studies and intermittent light photography and found three predominant patterns of gait in patients who had spastic hemiplegia that was secondary to cerebrovascular accidents; one pattern was similar to the pattern found in our Group-II patients and two patterns were similar to that in our Group-III patients.

Materials and Methods

Forty-six patients who had spastic hemiplegia underwent a computerized analysis of gait at the Newington Children's Hospital Kinesiology Laboratory. The thirty-three male and thirteen female patients had an average age of 11.2 years (range, 3.4 to 30.5 years). Thirty-eight had cerebral palsy; six, traumatic injury to the brain; and two, juvenile cerebrovascular accident. The patients with the two latter diagnoses were tested at least two years after the onset of the hemiplegia and were believed to have reached the limit of neurological recovery. None of the patients had had orthopaedic surgery before the analysis and all could walk independently without orthoses or other aids.

In the Kinesiology Laboratory, we used four systems of measurement that were connected to a supervising computer (Digital Equipment Corporation, Maynard, Massachusetts): a three-dimensional motion camera (United

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Technologies Research Center, East Hartford, Connecticut), a three-channel visual camera (Panasonic, Secaucus, New Jersey), a force measurement system with two force platforms (Advanced Mechanical Technology, Newton, Massachusetts), and an eight-channel electromyographic telemetry system (Biosentry, Torrance, California). The electromyographic telemetry system monitored signals from surface amplified electrodes (Motion Control, Salt Lake City, Utah) or implanted fine-wire electrodes, or both.45

All patients had an orthopaedic evaluation as part of the analysis in which they walked at self-selected speeds during testing. Two runs of kinematic data were done for each subject and were compared visually. In patients who have spastic hemiplegia the differences in data from run to run are usually minor. Any patients whose analysis showed gross differences between runs were eliminated from the study. In patients who had minor differences, the data that more closely approximated normal were selected.

Although analysis of three-dimensional motion measurements was done in all patients, the classification of the patients into the four groups to be described was based on the recordings that were made in the sagittal plane (that is, the plane of progression for the three major joints of the lower extremity). Electromyographic data were used to classify patients who could not be grouped by kinematic data alone.

Results

Four distinct patterns of gait were identified. Table I compares the speed of walking and rotations of the joints in the sagittal plane of the four groups with the parameters of normal gait.

Group I consisted of twelve boys and eight girls, whose average age was 9.5 years (range, 5.2 to 15.8 years). Nineteen patients had cerebral palsy and one had traumatic injury to the brain. The patients in this group had the mildest deviations from normal gait. The average speed of walking was 97.3 centimeters per second; the normal speed for children who are between the ages of eight and fourteen years is 116.6 centimeters per second. The most significant abnormality of gait was a drop foot in the swing phase (Fig. 1), but equally important was the finding that they had an adequate range of dorsiflexion (average, 12 degrees) (Table I) of the ankle during the stance phase of gait. The maximum amount of dorsiflexion in the stance phase was more than zero degrees in all of the Group-I patients. Other deviations from normal gait that were recorded in this group included increased flexion of the knee at terminal swing phase, at initial contact, and in loading response; hyperflexion of the hip during the swing phase; and increased lordosis of the pelvis throughout the gait cycle (Fig. 1).

Group II consisted of thirteen patients, nine boys and four girls, whose average age was 10.2 years (range, 4.3 to 15.8 years). Eleven patients had cerebral palsy; one patient, traumatic injury to the brain; and one, a cerebrovascular accident. The average speed of walking for the patients in Group II was 90.0 centimeters per second. The gait in this group was characterized by plantar flexion that persisted...
GAIT PATTERNS IN SPASTIC HEMIPLEGIA

TABLE I
DATA ON AGE AND PARAMETERS OF GAIT IN NORMAL SUBJECTS AND HEMIPLEGIC GROUPS*

<table>
<thead>
<tr>
<th></th>
<th>Normal†</th>
<th>Group I</th>
<th>Group II</th>
<th>Group III</th>
<th>Group IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation of the joints</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>during gait (degrees)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum dorsiflexion of</td>
<td>4 ± 6</td>
<td>-1 ± 6</td>
<td>-16 ± 11</td>
<td>-21 ± 8</td>
<td>-14 ± 10</td>
</tr>
<tr>
<td>the ankle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(swing phase)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum dorsiflexion of</td>
<td>10 ± 4</td>
<td>12 ± 6</td>
<td>-7 ± 10</td>
<td>-6 ± 12</td>
<td>-8 ± 14</td>
</tr>
<tr>
<td>the ankle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(stance phase)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Total flexion-extension</td>
<td>56 ± 4</td>
<td>51 ± 8</td>
<td>60 ± 10</td>
<td>37 ± 8</td>
<td>33 ± 12</td>
</tr>
<tr>
<td>of the knee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total flexion-extension</td>
<td>42 ± 3</td>
<td>44 ± 7</td>
<td>46 ± 6</td>
<td>46 ± 10</td>
<td>29 ± 4</td>
</tr>
<tr>
<td>of the hip</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (yrs.)</td>
<td>11</td>
<td>10 ± 4</td>
<td>10 ± 4</td>
<td>15 ± 12</td>
<td>12 ± 6</td>
</tr>
<tr>
<td>Speed of walking (cm/sec.)</td>
<td>117 ± 14</td>
<td>97 ± 19</td>
<td>90 ± 20</td>
<td>80 ± 24</td>
<td>84 ± 22</td>
</tr>
</tbody>
</table>

* Mean and standard deviation.
† Values obtained from Newington Children’s Hospital.

throughout the gait cycle (Table I). The patients in this group also demonstrated full extension or hyperextension of the knee in the stance phase (Fig. 1) as well as hyperflexion of the hip and increased lumbar lordosis throughout the gait cycle.

Group III consisted of five male patients, whose average age was 14.5 years (range, 4.9 to 30.5 years). Two patients had cerebral palsy; two, traumatic injury to the brain; and one, a cerebrovascular accident. The average velocity of walking was 79.7 centimeters per second. The patients in this group had plantar flexion at the ankle, showed a progression of involvement proximally, and had more limited flexion of the knee during the swing phase than Group-II patients. Total flexion-extension of the knee during gait was less than 45 degrees in Group-III patients; the value for normal subjects is 56.3 degrees. Group-III patients were similar to patients in Groups I and II in that they also had hyperflexion of the hip and increased lumbar lordosis.

Group IV consisted of eight patients, seven male and one female. The average age was 12.2 years (range, 3.4 to 21.5 years). Six patients had cerebral palsy and two, trauma-
matic injury to the brain. This group had the most neurological involvement. The average velocity for walking was 84.4 centimeters per second. The ankle was plantar flexed, motion of the knee was restricted, and the hip showed limited flexion-extension. Total flexion-extension of the hip during gait was less than 35 degrees in Group-IV patients; the value in normal subjects is 42.1 degrees. Group-IV patients compensated for limited motion of the hip by increasing pelvic lordosis during the terminal stance of gait (Fig. 2).

Discussion

**Group I**

The pattern of gait in the patients in Group I was best characterized by plantar flexion of the ankle in the swing phase, resulting in an equinus deformity at initial contact. The heel cord was not tight since there was adequate dorsiflexion in the stance phase. To compensate for the drop foot, the knee hyperflexed at foot strike, forcing the hip into increased flexion in order to maintain the body in a position centered over the foot and to help clear the swinging limb with the drop foot. The pattern of pelvic tilt showed increased lordosis throughout the gait cycle.

The classic treatment for these patients has been to lengthen the heel cord. Such treatment, however, can worsen the gait since the pathological lesion is not a shortening of the gastrocnemius and soleus muscles as evidenced by dorsiflexion of more than zero degrees during the stance phase. It is more likely that the problem is weakness or underactivity of the anterior tibial muscle relative to overactivity of the gastrocnemius and soleus muscles.

**Group II**

The patients in Group II had a static or dynamic contracture of the gastrocnemius and soleus muscles that resulted in persistent plantar flexion of the ankle during the stance and swing phases. Perry\(^6\) stated that 15 degrees of plantar flexion of the ankle places the trunk behind the foot unless the knee is hyperextended, the hip is flexed, or the heel is elevated by external support. When the ankle is in fixed plantar flexion, the tibia and foot function together as a long lever that will not allow the usual rocker motion of the tibia on the foot. This forces the knee into hyperextension in the middle and terminal stages of stance. In addition, advancement of the trunk is curtailed and the length of the opposite step is decreased. To maintain the center of gravity over the foot, flexion of the hip and pelvic lordosis were increased, as in the patients who were in Group II.

In the study of Knutsson and Richards one-third of the twenty-six patients who had hemiplegia secondary to a cerebrovascular accident demonstrated a pattern that was similar to that in our Group-II patients. The main disturbance was plantar flexion of the ankle that resulted in hyperextension of the knee.

**Group III**

The musculature in the proximal part of the lower extremity was more involved in the patients in Group III than in those in Groups I and II. Waters et al.\(^1\) believed that the stiff-legged gait of some hemiplegic patients is a regression to primitive locomotor patterns. These patterns are present in quadrupeds that depend on the extensor reflex for stability in stance and activation of the lower extremity. This extensor reflex occurs during terminal swing phase. There is a strong reflexive tie between contraction of the quadriceps muscles, extension of the hip, and plantar flexion of the ankle; therefore, the equinus position is normal during gait in quadrupeds. In bipeds, the extensor reflex at the ankle has been blocked so that humans do not normally initiate the stance phase with the foot plantar flexed.

In the Group-III patients the extensor reflex remained at the hip and knee to resist the flexor thrust; in fact, extensor tone is enhanced when one rises to the upright position. A central lesion in Group-III patients released the plantar reflex at the ankle from its inhibitory block\(^3\),\(^10\). The result was the stiff gait with short steps that the Group-III patients demonstrated.

In subjects who have a normal gait, the knee flexes to 35 degrees in the late phase of stance, just before toe-off. Flexion increases to 65 degrees by the middle of the swing after the activity of the quadriceps muscles has ceased.\(^12\) In the Group-III patients, however, the quadriceps and hamstring muscles remained active. This simultaneous contraction of flexor and extensor muscles limited flexion of the knee during swing. Electromyography using surface amplified electrodes confirmed this by showing the abnormal activity of these muscles during the swing phase (Fig. 2). We believe that loss of coordinated contraction of the quadriceps and hamstring muscles is the primary cause of the decreased flexion of the knee that occurs during the swing phase.\(^12\)

Knutsson and Richards also found hyperextension of the knee in the stance phase and decreased flexion of the knee in the swing phase in one-third of their patients. However, they also found decreased electromyographic activity of two or more muscle groups and believed the hyperextension of the knee compensated for weakness of the muscles rather than being secondary to plantar flexor spasticity. Decreased electromyographic activity was not found in our Group-III patients. In one-sixth of the patients in their series, Knutsson and Richards found concomitant activation (as shown by electromyography) in four to six muscle groups and decreased flexion of the knee during the swing phase. These findings were true of all of our patients who were in Group III.

**Group IV**

In Group-IV patients, as in Group-III patients, the extensor reflex was implicated because they had decreased motion at the hip and knee and plantar flexion at the ankle. The reduction of motion in the sagittal plane at the hip constituted the crucial difference between Groups III and IV. Increased activity of the iliopsoas and hip adductors prevented the hip from reaching full extension at terminal
stance phase. The length of the stride would have been severely shortened without the compensatory increase in anterior pelvic tilt.

In general, there was a progression of involvement in the four groups. The average speed of walking for Groups I and II combined was approximately ninety-five centimeters per second compared with approximately eighty-three centimeters per second for Groups III and IV (p < 0.1). Patients in Groups I and II appeared to have the least residual damage to the central nervous system as compared with patients in Groups III and IV. It is of interest that the patients in Groups I and II combined were significantly younger than those in Groups III and IV combined (approximately ten and thirteen years, respectively, p < 0.05).

Since spastic hemiplegia in young patients encompasses a spectrum of deficits, it follows logically that treatment of the condition should be specific to the neurological deficit. For example, patients who have a pattern of gait similar to our Group I do not require a lengthening of the Achilles tendon since the gastrocnemius and soleus muscles are not shortened. A leaf-spring orthosis (a flexible plastic ankle-foot orthosis) should adequately control the drop foot.

Patients who have a gait similar to our patients in Group II usually will require lengthening of the plantar flexors of the involved ankle as well as a leaf-spring orthosis. In order to develop the patient's ability to walk to the maximum, treatment will probably have to extend to the knee for patients who have a gait similar to our Group-III patients and to the knee and the hip for those who have a gait similar to our Group-IV patients.

References


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