Abstract

Sequential changes in gait patterns were investigated retrospectively by analyzing the videotape recordings of 20 children with spastic diplegia and periventricular leukomalacia (PVL). The subjects began to walk at 1–5 years of age, and their walking was examined to 6–16 years of age. Many of the ambulatory children with spastic diplegia walked with flexed hips, knees and ankles. At the final walking examination, the knee was flexed during the stance phase in both legs and in all cases. In addition, the ankle was over-plantarflexed during the stance phase in nine cases or 14 legs, and dorsiflexed in 15 cases or 26 legs. At the initial walking, the knee was over-extended during the stance phase in seven cases or 12 legs, and was flexed in 15 cases or 28 legs. Also, the ankle was over-plantarflexed during the stance phase in 14 cases or 22 legs, and dorsiflexed in ten cases or 18 legs. Bilateral excessive ankle plantarflexion or a recurvatum knee was observed in a portion of the children at the initial phase of walking only. In the diplegic children with PVL, the gait pattern was variable. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Gait patterns; Spastic diplegia; Cerebral palsy; Periventricular leukomalacia

1. Introduction

Spastic diplegia is the principal type of cerebral palsy in preterm infants, and its main disability is a dysfunction of the lower extremities [1]. Motor abnormalities of spastic diplegia are not uniform, and children with spastic diplegia have variable locomotive or gross motor patterns [2,3]. Various gait patterns have also been reported in ambulatory spastic diplegic children. These gait patterns include crouch gait, stiff knee, recurvatum knee, internally rotated hip, and equinus or equinovalgus foot [4–7]. However, changes in gait patterns with advancing age in spastic diplegic children have not been fully examined. In this study, the sequential changes of gait patterns from the beginning of walking were investigated in spastic diplegic children. In order to select subjects with uniform brain lesions, the subjects were limited to children diagnosed with periventricular leukomalacia (PVL) [8]. Due to difficulties in the analysis of precise gait patterns in infants or young children with spastic diplegia, video-tape recordings of walking were selected for analysis.

2. Subjects and methods

Twenty ambulatory children (nine males and 11 females) born at preterm with spastic diplegia were studied. The subjects demonstrated bilateral hypertonicity, primarily in the lower extremities with a lesser involvement of the upper extremities, and an absence of involuntary movements. The subjects were selected from outpatients attending the author’s hospital for rehabilitation between 1985 and 1999. MR imaging was performed between the ages of 2 and 8 years. The cerebral lesions revealed by MR were compatible with PVL, in that periventricular high-intensity areas on T2-weighted images and a reduction of the cerebral white matter were found. Children with lesions involving the cerebral cortex, such as a border-zone infarction, were excluded. The subjects underwent physical therapy based on the neurodevelopmental treatment, formulated by Bobath, prior to acquisition of independent gait. The subjects were examined every 2 or 4 months for at least 5 years after the acquisition of independent gait. The subjects were examined every 2 or 4 months for at least 5 years after the acquisition of independent gait. When last examined, their ages ranged from 6 to 16 years, and they could walk indoors and outdoors for most activities without a brace. Two patients were excluded from the subject group after they were able to walk alone following orthopedic surgery on the lower extremities at 6 years of age. Of the subjects, four, 13,
two, and one were able to walk independently for at least 2 m at 1, 2, 3, and 5 years of age, respectively.

Seven subjects were born at 26–28 weeks of gestation, nine at 29–32 weeks, and four at 33–36 weeks. Four subjects weighed 550–999 g at birth, eight weighed 1000–1499 g, six weighed 1500–1999 g and two weighed 2000–2464 g.

The intelligence of each subject was assessed using either the Wechsler preschool or primary scale of intelligence, the Wechsler intelligence scale for children-revised, or the K-form developmental test. With regards to the latter test, the arithmetical mean values of the developmental quotients of the cognitive adaptive area and the language social area were used. The intelligence or developmental quotients of 18 children was 70 and over, and that of remaining two was between 50 and 70. None of the subjects were diagnosed with epilepsy.

Lateral and anterior views of walking subjects were recorded using videotape at least once per year.

---

**Fig. 1. Sequential changes in the gait pattern of children with spastic diplegia.** Some subjects had orthopedic surgery for contracture of hip flexion, knee flexion, or ankle plantarflexion at the following years of age: case 2, left hip, knee and ankle at 12 years; case 6, right hip and bilateral knees at 12 years; case 9, bilateral knees at 7 years; case 15, right hip and bilateral ankles at 10 years.
multiple walking patterns were recorded for a subject, the most stable walking pattern without the use of a brace was selected for investigation. The range of joint-motion during walking was approximated by means of slow-motion pictures and freeze-frame. For four children who underwent orthopedic surgery, the walking patterns recorded prior to the surgery were examined.

Motion of the hips and trunk during walking were analyzed by a lateral recorded view. In all of the subjects, the hips were not observed to fully extend. The trunk was judged to be bent forward, termed ‘B’. When a perpendicular line from the anterior tip of the mandibula fell in front of the toes when walking. When the perpendicular line fell behind the tips of the toes, an insufficient extension of the hip was judged to be compensated for by lumbar lordosis, termed ‘L’. Walking was judged to be stable when both arms swung reciprocally and the shoulders abducted less than 30° during walking. In this gait, the arms were not used for balance. Walking without these features was judged to be unstable (designated as ‘ = ’).

Motions of the knee and ankle were examined from the right and left side, respectively. Motion of the knee was represented by the angle of maximum extension during the stance phase of the gait cycle. When the knee was extended 0° and over at this moment, the knee was judged to be hyper-extended, termed ‘E’. When the knee was flexed more than 0° at this moment, the knee was judged to be flexed, termed ‘F’. When knee flexion was 30° and over, the knee was judged to be hyper-flexed, termed ‘F + ’. Motion of the ankle was represented by the angle of maximum dorsiflexion during the stance phase of the gait cycle. When the ankle was dorsiflexed 0° and over at this moment, the ankle was judged to be dorsiflexed, termed ‘D’. When the ankle was plantarflexed more than 0° at this moment, the ankle was judged to be plantarflexed, termed ‘P’. When plantarflexion was 60° and over, the ankle was judged to be hyper-plantarflexed, termed ‘P + ’.

Contractures of the hips, knees and ankles were estimated during the regular examination. Contracture of the hip was represented by the angle of flexion contracture using the Thomas test. In this test, a limitation of the hip extension was measured with the patient supine and the contralateral hip flexed. When this angle was 30° and over, the hip was judged to be contracted to flexion. Contracture of the knee was represented by the popliteal angle. This angle was measured with the patient supine and the contralateral limb extended. The hip is then flexed to 90° and the knee was passively extended from a position of 90° of the flexion. The angle subtended by the tibia with the long axis of the femur was referred to as the popliteal angle. When this angle was 50° and over, the knee was judged to be contracted to flexion. Contracture of the ankle was represented by the angle of dorsiflexion with the knee extended fully. When this angle was 0° and under, the ankle was judged to be contracted to plantarflexion.

None of the subjects suffered dislocation of the hips.

Radiographs of the subjects’ hips, examined at the age of 5–12 years, showed a Remer’s migration percentage of 30% or less.

### 3. Results

The gait patterns of the subjects are shown in Fig. 1 and Table 1. The angle subtended by the long axes of both feet during walking, which was visually estimated from frontal and lateral views, was within approximately 60° in all subjects except one case. The angle was about 120° in the final walking pattern of this exceptional patient (case 10). A lateral view was used in the estimation of knee and ankle motions, because any internal rotation of the hips during walking was mild in most of the subjects.

Final walking patterns in all subjects, including those in patients examined prior to orthopedic surgery, were comprised of ‘FD’ and ‘FP’. The knees of the subjects were always flexed during walking, and a third of the ankles observed were extended. The trunk in all subjects exhibited lordosis (designated as ‘L’). Contracture of the hip was demonstrated in four cases and in five legs, while contracture of the knee was observed in five cases and nine legs. Contracture of the ankle was present in seven cases and nine legs. Extended knees were observed only during the initial phase after the beginning of walking, and were always associated with a plantarflexed ankle and trunk bending (designated as ‘B’ and ‘EP’). Bilateral plantarflexion of the ankles, associated with flexed knees as an initial walking pattern, was always excessive (designated as ‘FP + ’).

Motions of the knee and ankle during walking changed as the age advanced (Fig. 1, Table 2). Whether the knee was flexed or extended during the initial walking, the knee became flexed in the final walking gait in all of the subjects. Many of subjects with dorsiflexed ankles during the initial walking, continued to dorsiflex ankles during the final walking. In subjects with plantarflexed ankles during the initial walking, the ankles were either plantarflexed or dorsiflexed during the final walking. Two of 14 subjects with a bilaterally identical pattern at the initial walking exhibited different patterns (‘FD’ and ‘FP’) on each side at the final walking.

<table>
<thead>
<tr>
<th>Initial walking patterns</th>
<th>Final walking patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilateral FD</td>
<td>6 cases</td>
</tr>
<tr>
<td>Bilateral EP</td>
<td>5 cases</td>
</tr>
<tr>
<td>Bilateral FP</td>
<td>3 cases</td>
</tr>
<tr>
<td>FD and FP</td>
<td>4 cases</td>
</tr>
<tr>
<td>FP and EP</td>
<td>2 cases</td>
</tr>
<tr>
<td>FD</td>
<td>18 legs</td>
</tr>
<tr>
<td>EP</td>
<td>12 legs</td>
</tr>
<tr>
<td>FP</td>
<td>10 legs</td>
</tr>
</tbody>
</table>

Table 1

Initial and final walking patterns in the subjects
4. Discussion

Many of the ambulatory children with spastic diplegia were able to acquire a walk with flexed hips, knees and ankles. This gait pattern, known as crouch gait, is used in the majority of diplegic children. Crouch gait has been interpreted to result from over-activity or shortening of the hamstrings [9,10]. Over-activity of the hamstrings is thought to progress with advancing age in diplegic children [11], because the knees inevitably become flexed in walking, even in the children with extended knees during initial walking. In addition, recurvatum knee is thought to be a minor problem in diplegic children for the same reason.

An extreme toe walking with bilateral excessive ankle plantarflexion (shown as ‘FP +’) was observed at an initial phase of walking in some of the diplegic children. This pattern may result from over-activity of the plantarflexors, which is prominent only at an initial phase of walking. FP + developed into contracture of the ankle in a portion of the subjects, and became diminished in the remaining subjects. Interestingly, ankle plantarflexion developed later in some of the subjects.

A stiff knee pattern is known to be one type of gait pattern observed in diplegic children, and is characterized by a reduced range of knee motion during walking [4–7]. This pattern is thought to result from over-activity of the knee extensors. However, the stiff knee pattern could not be differentiated from crouch gait and recurvatum knee because the range of knee motion was not examined in this study.

As shown in this study, the gait pattern of diplegic children is determined by a combination of the dominant activity of hip flexors, knee flexors and ankle plantarflexors. This dominance may reflect the insufficient activity of the antagonist. In some of the subjects, dominance develops into a contracture of the joint, which modifies the gait pattern. Dominance of knee extension and ankle plantarflexion, recognized only at an initial phase of walking, influences the initial gait pattern. In diplegic children with the uniform causative brain lesion, PVL, the gait pattern is variable. In addition, combinations of joint contracture is also variable. PVL affects the parieto-occipital white matter and the cerebral white matter at the corticospinal tract [8]. While contributing to the visuoperceptual symptoms, the parietal lesions may also play a role in observed motor symptoms such as ataxia [12]. These lesions may contribute to the motor symptoms in children with spastic diplegia. Clearly, more research on the motor symptoms of spastic diplegia is needed.

References