Comparison of Children with Joint Angles in Spastic Diplegia with Those of Normal Children

CHANG JU KIM, MS, PT1, YOUNG MI KIM, MS, PT2, DONG DAE KIM, PhD, PT2
1) Department of Physical Therapy, College of Rehabilitation Science, Daegu University: 15 Jilyang, Gyeongsan-si, Kyeongbuk 712-714, Republic of Korea
2) Department of Physical Therapy, Gangdong College, Republic of Korea

Abstract. [Purpose] The purpose of this study was to compare joint angles between normal children and those with spastic diplegia using three-dimensional gait analysis. [Subjects and Methods] The study subjects were eight patients with spastic diplegia and eight normal children. Three-dimensional gait analysis was used for the survey. The measured gait variables were the joints of the lower extremity in the sagittal plane, frontal plane, and transverse planes and the maximum and minimum angles of their stance phase and swing phases. [Results] In the sagittal plane, the maximum angles of both the right and left pelvis and hip joint in the stance phase and swing phases were significantly greater for children with spastic diplegia than for normal children. In the stance phase of the right side of the hip joint, the maximum angles of the hip in the swing phase and the knee joint’s minimum angles in the stance phase differed significantly. In the transverse plane, there were a significant differences on the left side of the pelvis in the maximum angles in the swing and stance phases. There were also significant differences on the right side pelvis, in the maximum and minimum angles in the stance phase and minimum angles in the swing phase. [Conclusion] Children with spastic diplegia employ a different gait strategy and pattern from normal children. Key words: Spastic diplegia, Joint angle

INTRODUCTION

Cerebral palsy is a condition in which permanent problems affect movements and postural development due to non progressive lesions in the immature brain. It is accompanied by sensory disabilities, cognitive disorders, communication disorders, hypermetamorphosis, behavioral disorders, or convulsion. Among the types of cerebral palsy, spastic cerebral palsy is the most common and shows motor disorders, such as spasticity, deep tendon reflex accentuation, and muscle weakening. As a result, cerebral palsy patients show kinetic and kinematic changes as well as diverse forms of gait abnormalities.

One major objective in the rehabilitation of cerebral palsy children is gait ability improvement. To do this, therapists apply diverse methods, such as walking aids, drug treatment, and neuro-developmental treatment. Gait analysis is recognized as an important tool in the clinical assessment and the measurement of treatment outcomes for patients with neuromuscular disabilities and, more specifically, in cerebral palsy patients undergoing surgery.

The purpose of this study was to analyze and compare the gait of spastic diplegia children with that of normal children by using three-dimensional motion analysis, this will provide the basic data necessary for therapeutic interventions, such as surgery, neurophysiological treatment, and assistive device prescription.

SUBJECTS AND METHODS

Children with spastic diplegia type cerebral palsy children aged 6–12 years were selected as the experimental group (CP). Criteria for inclusion were a low degree of disorders based on their medical history of treatment by physical therapists and specialists in the department of rehabilitation, ability to understand the researcher’s instructions, and ability to walk independently without assistance. The control group consisted of eight normal children aged 8–11 years without any past or current medical history of abnormal gait (normal).

The general characteristics of the subjects were: age, CP 8.25±0.75 years, normal 9.13±0.44 years; height, CP 125.60±7.05 cm, normal 137.09±2.78 cm; weight, CP 30.50±3.35 kg, normal 34.56±2.79 kg. All participants understood the purpose of this study and provided their written informed consent prior to participation in accordance with the ethical principles of the Declaration of Helsinki.

A computer loaded with Orthotrak 6.4 (Motion Analysis, Santa Rosa, CA, USA) and EvaRT 6.1.1 (Motion Analysis, Santa Rosa, CA, USA) and eight infrared cameras connected to the computer were used to record the subjects’ walking motions for three-dimensional gait analysis. The
Data were processed using the Orthotrak 6.4 and EvaRT 6.1.1 software.

A tester attached 25-mm diameter, round, reflective markers to the subjects’ lower extremity segmental points including their pelvis. These markers were attached to the subjects, who wore only briefs, after having removed their outerwear and 19 reflective markers were placed on each subject based on the Helen-Hays marker set. The locations of the markers included the sacrum, ASIS (anterior superior iliac spine), mid thigh, lateral femoral epicondyle, mid shank, lateral malleolus, second metatarsal head, and posterior calcaneus.

The subjects were instructed to look at a mark on the wall while walking so that their line of sight would not be change, and their walking was measured repeatedly until appropriate data were obtained. Subjects were given a rest of two minutes after walking six times. Four trials of walking at constant speeds were selected for analysis.

Changes in the maximum angles and minimum angles of individual joints during the stance and swing phases in the three movement planes—sagittal, frontal, and transverse—were analyzed and compared. The data were statistically processed using the independent sample t-tests for comparisons between the two groups. The statistical level was set to \( p < 0.05 \), and SPSS 17.0 version was used for the analysis, and significance was accepted for values of \( p < 0.05 \).

## RESULTS

### Table 1. Maximum and minimum angles of the pelvis, hip, knee, and ankle joint motions in the stance phase and swing phase in the sagittal plane (angle/unit)

| Joint | Group   | Left Mean ± SE | Left p  | Right Mean ± SE | Right p  |
|-------|---------|----------------|---------|-----------------|---------|
|       |         | Mean ± SE      |         | Mean ± SE       |         |
| pelvis| max stance | 13.07 ± 1.16 * |         | 13.10 ± 1.21 * |         |
|       | min stance | 9.71 ± 1.40     |         | 10.47 ± 1.48 |         |
|       | max swing | 13.12 ± 1.22 * |         | 13.43 ± 1.03 * |         |
|       | min swing | 10.56 ± 1.18    |         | 10.67 ± 1.28 |         |
| Hip   | max stance | 30.73 ± 2.98 * |         | 28.93 ± 2.68 * |         |
|       | min stance | −9.61 ± 2.93    |         | −10.32 ± 3.49 |         |
|       | max swing | 36.89 ± 2.33    |         | 34.25 ± 2.94 * |         |
|       | min swing | −4.97 ± 2.73    |         | −6.55 ± 3.74 |         |
| Knee  | max stance | 35.82 ± 5.31    |         | 20.86 ± 6.33 |         |
|       | min stance | −1.25 ± 2.53    |         | −5.48 ± 6.30 |         |
|       | max swing | 73.92 ± 8.72    |         | 56.05 ± 12.97 |         |
|       | min swing | −4.54 ± 3.21    |         | 9.73 ± 24.94 |         |
| Ankle | max stance | 15.05 ± 4.27    |         | 7.69 ± 2.28 |         |
|       | min stance | −10.89 ± 2.27   |         | −12.66 ± 2.35 |         |
|       | max swing | 14.37 ± 8.87    |         | 3.85 ± 2.16 |         |
|       | min swing | −16.33 ± 2.60   |         | −22.54 ± 4.32 |         |

*Mean ± SE +, Flexion; Mean ± SE –, Extension
*CP, Cerebral Palsy
*p<0.05

In the sagittal plane, the maximum angles of both the
right and left sides of the pelvis and hip joints in the stance phases and swing phases were found to be significantly greater among the spastic diplegia children than among the normal children \((p<0.05)\). There were no significant differences in the minimum angles of the right and left sides of the pelvis and hip joints in the swing phases and stance phases or in the maximum and minimum angles of the knee and ankle joints in the stance phases or swing phases (Table 1).

In the frontal plane, there were no significant differences in the maximum and minimum angles of the left pelvis and the joints of the lower extremity in the swing and stance phases between the two groups. There were no significant differences in the maximum and minimum angles of the right pelvis and the ankle joint in the swing and stance phases, in the minimum angles of the hip joint in the swing and stance phases, in the knee joint’s maximum angles in the stance phases, or in the maximum and minimum angles in swing phases. However, significant differences were shown in the maximum angles of the right side of the hip joint in the stance and swing phases and in the knee joint’s minimum angles in stance phases \((p<0.05)\) (Table 2).

In the transverse plane, there were significant differences in the maximum angles of the left side of the pelvis in the swing and stance phases \((p<0.05)\). There were also significant differences in the maximum and minimum angles of the right pelvis in the stance phases, and in the minimum angles of the right pelvis in the swing phases \((p<0.05)\). There were no significant differences in the maximum and minimum angles of the left/right hip, knee, or ankle joints in swing and stance phases (Table 3).

### Table 2. Maximum and minimum angles of the pelvis, hip, knee, and ankle joint motions in the stance phase and swing phase in the frontal plane (angle/unit)

| Joint          | Group   | Left Mean ± SE | p   | Right Mean ± SE | p   |
|---------------|---------|----------------|-----|-----------------|-----|
| **Pelvis**    |         |                |     |                 |     |
| max stance    | normal  | 3.22 ± 0.47    | 4.04 ± 0.31 |     |                 |     |
| CP            |         | 10.47 ± 10.20  | 15.78 ± 6.74 |     |                 |     |
| min stance    | normal  | −5.40 ± 0.44   | −4.88 ± 0.29 |     |                 |     |
| CP            |         | −9.25 ± 10.67  | −20.20 ± 7.29 |     |                 |     |
| max swing     | normal  | 4.65 ± 0.35    | 5.12 ± 0.32 |     |                 |     |
| CP            |         | 10.76 ± 7.92   | 7.80 ± 9.30  |     |                 |     |
| min swing     | normal  | −1.23 ± 0.42   | −1.05 ± 0.39 |     |                 |     |
| CP            |         | −16.18 ± 9.03  | −6.86 ± 9.43 |     |                 |     |
| **Hip**       |         |                |     |                 |     |
| max stance    | normal  | 11.86 ± 3.56   | −8.15 ± 1.62 | *   |                 |     |
| CP            |         | 6.84 ± 2.90    | 0.72 ± 3.09  |     |                 |     |
| min stance    | normal  | −1.41 ± 3.40   | −14.74 ± 1.69 |     |                 |     |
| CP            |         | −6.35 ± 2.12   | −14.26 ± 3.66 |     |                 |     |
| max swing     | normal  | 5.81 ± 3.02    | −6.34 ± 1.80 | *   |                 |     |
| CP            |         | 1.21 ± 2.98    | 5.59 ± 4.72  |     |                 |     |
| min swing     | normal  | −3.98 ± 3.31   | −19.24 ± 2.37 |     |                 |     |
| CP            |         | −9.60 ± 1.91   | −11.32 ± 7.63 |     |                 |     |
| **Knee**      |         |                |     |                 |     |
| max stance    | normal  | 4.75 ± 3.04    | 16.49 ± 8.67 |     |                 |     |
| CP            |         | 3.81 ± 4.55    | 10.55 ± 5.08 |     |                 |     |
| min stance    | normal  | −6.54 ± 2.24   | −1.16 ± 1.38 | *   |                 |     |
| CP            |         | −16.93 ± 6.76  | −21.27 ± 8.11 |     |                 |     |
| max swing     | normal  | 10.62 ± 6.02   | 26.23 ± 11.99 |     |                 |     |
| CP            |         | 13.02 ± 6.59   | 22.89 ± 10.34 |     |                 |     |
| min swing     | normal  | −10.36 ± 2.02  | −3.72 ± 2.60  |     |                 |     |
| CP            |         | −9.96 ± 4.27   | −7.05 ± 4.47  |     |                 |     |
| **Ankle**     |         |                |     |                 |     |
| max stance    | normal  | 1.63 ± 1.09    | −0.53 ± 1.89 |     |                 |     |
| CP            |         | 18.19 ± 15.41  | 3.63 ± 1.74  |     |                 |     |
| min stance    | normal  | −6.46 ± 2.96   | −10.08 ± 5.03 |     |                 |     |
| CP            |         | −9.35 ± 4.08   | −6.98 ± 3.28  |     |                 |     |
| max swing     | normal  | 1.49 ± 1.29    | −0.56 ± 1.05  |     |                 |     |
| CP            |         | 13.48 ± 8.26   | 0.23 ± 2.41  |     |                 |     |
| min swing     | normal  | −10.04 ± 3.03  | −15.04 ± 6.94 |     |                 |     |
| CP            |         | −9.07 ± 2.29   | −10.24 ± 4.04 |     |                 |     |

*Mean ± SE +, Abduction; Mean ± SE −, Adduction
*CP, Cerebral Palsy
*p<0.05
DISCUSSION

Although the largest movements appear in the sagittal plane during gait analysis, movements in the frontal plane and in the transverse plane are particularly important in studies of morbid gait\(^7\). Therefore, we focused on comparing differences in gait between normal children and those with spastic diplegia-type cerebral palsy, and compared maximum angles and minimum angles in the stance phases and swing phases using kinematic analysis.

In kinematic aspects of normal gait, the pelvis moves asynchronously in three movement planes. Perry (1994) reported that the pelvis tilts 7° forward in the sagittal plane, moves 4° downward and upward in the frontal plane, and rotates 10° in the transverse plane. In this study, pelvis movements in the sagittal plane showed larger forward tilting in the spastic diplegia children than in the normal children in both the swing phases and stance phases. Hemiplegic cerebral palsy children’s excessive pelvic tilting has been reported to be due to the spasticity of the hip joint flexor or the weakening of the hip joint extensor and the abdominal muscles\(^8\).

Pelvis movements in the frontal plane were also found to be greater in the spastic diplegia children than in the normal children in both the swing phases and stance phases. This is consistent with reports results that pelvis angles are much greater in cerebral palsy children than in normal children in the sagittal, frontal, and transverse planes\(^9\). These previous studies have reported that pelvic movements in the transverse plane showed significant differences because cerebral

Table 3. Maximum and minimum angles of the pelvis, hip, knee, and ankle joint motions in the stance phase and swing phase in the transverse plane (angle/unit)

| Joint | Group  | Left Mean ± SE | p  | Right Mean ± SE | p  |
|-------|--------|----------------|----|-----------------|----|
|       |        |                |    |                 |    |
| pelvis| max stance normal | 6.95 ± 0.80 | *  | 7.35 ± 0.61 |    |
|       | CP     | 16.52 ± 1.66  |    | 17.41 ± 4.15  |    |
|       | min stance normal | −8.85 ± 0.95 |    | −4.73 ± 2.01  | *  |
|       | CP     | −13.34 ± 3.29 |    | −15.91 ± 1.97 |    |
|       | max swing normal | 6.10 ± 1.00 | *  | 8.29 ± 1.06  |    |
|       | CP     | 16.38 ± 2.75  |    | 10.20 ± 3.83  |    |
|       | min swing normal | −7.67 ± 1.02 |    | −4.58 ± 0.74  | *  |
|       | CP     | −8.72 ± 3.10  |    | −13.11 ± 2.01 |    |
| Hip   | max stance normal | 6.15 ± 5.42 |    | 23.62 ± 13.81 |    |
|       | CP     | 22.30 ± 7.20  |    | 25.14 ± 16.91 |    |
|       | min stance normal | −5.12 ± 5.75 |    | 13.27 ± 13.53 |    |
|       | CP     | 6.29 ± 6.47   |    | 12.62 ± 17.28 |    |
|       | max swing normal | 5.50 ± 4.57  |    | 25.40 ± 13.45 |    |
|       | CP     | 20.42 ± 7.46  |    | 25.00 ± 17.47 |    |
|       | min swing normal | −6.40 ± 4.70 |    | 12.73 ± 13.20 |    |
|       | CP     | 5.01 ± 7.92   |    | 12.73 ± 17.42 |    |
| Knee  | max stance normal | −0.59 ± 1.79 |    | −0.42 ± 5.93  |    |
|       | CP     | 3.08 ± 7.89   |    | 14.46 ± 8.91  |    |
|       | min stance normal | −13.98 ± 2.87 |    | −15.39 ± 5.11 |    |
|       | CP     | −23.93 ± 4.67 |    | −13.28 ± 8.63 |    |
|       | max swing normal | −1.87 ± 3.03 |    | 11.83 ± 22.40 |    |
|       | CP     | −1.02 ± 6.23  |    | 11.97 ± 10.44 |    |
|       | min swing normal | −15.51 ± 2.77 |    | −42.71 ± 10.11|    |
|       | CP     | −21.22 ± 3.81 |    | −23.01 ± 6.53 |    |
| Ankle | max stance normal | 4.88 ± 5.58  |    | −12.86 ± 19.49|    |
|       | CP     | 23.89 ± 15.85 |    | −24.64 ± 19.19|    |
|       | min stance normal | −10.21 ± 7.72 |    | −28.69 ± 19.89|    |
|       | CP     | −10.66 ± 8.06 |    | −46.17 ± 22.15|    |
|       | max swing normal | 7.87 ± 4.99  |    | −5.68 ± 17.93 |    |
|       | CP     | 21.93 ± 9.56  |    | −30.26 ± 21.58|    |
|       | min swing normal | −9.60 ± 7.81 |    | −30.93 ± 23.01|    |
|       | CP     | −7.66 ± 7.39  |    | −45.76 ± 26.10|    |

*Mean ± SE +, Internal rotation; Mean ± SE −, External rotation
*CP, Cerebral Palsy
*p<0.05
palsy children perform excessive external rotation of the pelvis compared to normal children in order to compensate for their excessive internal rotation of the hip joint\(^1\). Perry J reported that the maximum angle of the hip joint in normal gait was 40\(^\circ\) and that spastic diplegia children showed maximum hip joint angles greater than 40\(^\circ\) in the sagittal plane in the stance phases and swing phases\(^1\).

A study of hemiplegic cerebral palsy children's gait reported that the spasticity of the hip joint flexor causes increased forward tilting of the pelvis, which is a cause of increasing in lumbar lordosis\(^1\). In our study, too, significant differences were found in the frontal plane and the transverse plane. Although we consider these differences are thought to be attributable to the imbalance of asymmetric muscles of the paretic lower extremity and restriction of joint movement, the precise cause could not be determined.

Sutherland reported that spastic cerebral palsy children and patients with severe twitching of the hamstring muscle tendon showed increases in knee joint flexion during the stance phases\(^1\). Our results are similar, results as the cerebral palsy children group showed increases in the maximum angles of knee joint flexion compared to the normal group during the stance phases, although the differences were not significant.

Based on the results of this study, there are differences in the kinematic variables of children with spastic diplegia and normal children. We can conclude that spastic diplegia children have a different gait strategy and pattern from normal children. Primary abnormalities of children with CP, which arise directly from the damage to the central nervous system (e.g., abnormal muscle tone, abnormal reflex activity, loss of selective muscle control, spasticity), and from secondary effects (contracture and deformations), resulting from abnormal bone and muscle growth. Due to asymmetric physical movement and abnormal phasic muscle activity of the paretic lower extremity and the reduction in the range of motion of both lower extremity joints, postural control and physical balance ability are impaired in spastic diplegia children. These children also experience excessive movements and restrictions during the stance phases and swing phases as compensational physical reactions compared to normal children, resulting in the different gait strategy and pattern. A potential weakness of this study was the small number of participants which resulted in limits the power of the statistical findings.

REFERENCES

1) Rosenbaum P: Cerebral palsy in the 21st century: is there anything left to say? Neuropediatrics, 2009, 40: 56–60. [Medline] [CrossRef]
2) Himmelmann K, Hagberg G, Beckung E, et al.: The changing panorama of cerebral palsy in Sweden. IX. Prevalence and origin in the birth-year period 1995-1998. Acta Paediatr, 2005, 94: 287–294. [Medline] [CrossRef]
3) Baddar A, Granata K, Damiano DL, et al.: Ankle and knee coupling in patients with spastic diplegia: effects of gastrocnemius-soleus lengthening. J Bone Joint Surg Am, 2002, 84-A: 736–744. [Medline]
4) Buzzi UH, Ulrich BD: Dynamic stability of gait cycles as a function of speed and system constraints. Mot Contr, 2004, 8: 241–254. [Medline]
5) Bennett BC, Russell SD, Abel MF: The effects of ankle foot orthoses on energy recovery and work during gait in children with cerebral palsy. Clin Biomech (Bristol, Avon), 2012, 27: 287–291. [Medline] [CrossRef]
6) Gage JR, DeLuca PA, Renshaw TS: Gait analysis: principle and applications with emphasis on its use in cerebral palsy. Instr Course Lect, 1996, 45: 491–507. [Medline]
7) Whittle JR, Haddow LJ: CT guided thalamotomy for movement disorders in multiple sclerotic problems and paradoxes. Acta neurochirurgica. Supplement, 1995, 64: 13–16.
8) Winters TF Jr, Gage JR, Hicks R: Gait patterns in spastic hemiplegia in children and young adults. J Bone Joint Surg Am, 1987, 69: 437–441. [Medline]
9) Pizzinetti L, Cimolin V, D’Angelo MG, et al.: 3D gait analysis in patients with hereditary spastic paraparesis and spastic diplegia: a kinematic, kinetic and EMG comparison. Eur J Paediatr Neurol, 2011, 15: 138–145. [Medline] [CrossRef]
10) DeLuca PA: Gait analysis in the treatment of the ambulatory child with cerebral palsy. Clin Orthop Relat Res, 1991, (264): 65–75. [Medline]
11) Perry J: Gait analysis: technology and the clinician. J Rehabil Res Dev, 1994, 31: vii. [Medline]
12) Olney SJ, Griffin MP, McBride ID: Temporal, kinematic, and kinetic variables related to gait speed in subjects with hemiplegia: a regression approach. Phys Ther, 1994, 74: 872–885. [Medline]
13) Sutherland DH: Gait analysis in cerebral palsy. Dev Med Child Neurol, 1978, 20: 807–813. [Medline] [CrossRef]