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Original Article

Kinematic Characteristics of Jump Gait in Children with Spastic Diplegia

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Abstract

Introduction and Purpose: One of the few described patterns of gait in children with spastic cerebral palsy is Jump gait. Sagittal motion kinematics of gait in spastic children have been studied by various authors. They have described that in jump gait, rapid knee extension and plantar flexion occur during initial contact, however, as the child gains weight and matures the pattern slows and changes. Instrumented gait analysis enhances the understanding of gait abnormality by providing real-time objective data that cannot be appreciated visually. Very few data describing the jump gait in children with spastic diplegia belonging to the Indian population exists. The aim of this study is to describe the kinematic characteristics of jump gait in children with spastic cerebral palsy.

Methodology: Clinical and physical evaluation, kinematic and spatiotemporal data from three-dimensional gait analysis of 14 children from India with spastic cerebral palsy walking with jump gait diagnosed clinically were compiled and entered into a pro forma after informed consent. Children were grouped according to age, sex, and gross motor functional classification system (GMFCS). The aspects studied were ankle-foot rockers, initial contact during stance phase, knee flexion, hip flexion and hip adduction in relation to incidence, cadence, and mean velocity.

Results: A total of 14 children with spastic jump gait were studied. The mean age was 8.4 years; there were 9 boys and 5 girls. 6 children belonged to GMFCS I and 8 belonged to GMFCS II. 2 children had hip flexion deformity and 6 had knee flexion deformity. The majority of the initial contact during stance phase was on the midfoot (53.6%). Although toe rockers were good in all age groups, children >12 years had deterioration of the other rockers. The rockers were best in the 7–12 age group. Children with hip flexion had decreased cadence and mean velocity so too did the children with knee flexion deformity. Those children who had stiffer gastrocnemius muscle, i.e., static equinus had better cadence than those children who had dynamic equinus. However, most analyses had no significant *P* values. Except for the analysis of knee flexion contracture to cadence ($P = 0.05$).

Conclusion: Children with jump gait mostly landed on their midfoot during initial contact. The ankle rockers were best in the 7–12 age group and knee flexion deformity played a significant role in making the gait slower. Stiffer equinus helped the children to have faster cadence.

Key words: Adductor tightness, Ankle-foot rocker, Cerebral palsy, Equinus, Jump gait, Kinematics, Knee contracture, Spastic diplegia, Three-dimensional gait analysis

INTRODUCTION AND RATIONALE

Jump gait is one of the common gait patterns in spastic cerebral palsy. In a study by de Morais Filho *et al*. of about 1803 children 9.3% were walking with jump gait and 48.6% were having asymmetrical gait.[1] Sutherland and Davids described four pathological gait patterns in spastic diplegia based on knee motion in the sagittal plane (Jump, crouch, equinus, and stiff-knee gait).[2] Rodda *et al*. classified the gait patterns in diplegia into five groups based on the kinematic analysis in the sagittal plane motions of the pelvis hip, knee, and ankle.[3]

Cerebral palsy is a group of disorder of development of movement and posture causing activity limitation that is attributed to non-progressive disturbance that occurs in the developing fetus or the infant brain.[4] Perry has classified

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gait cycle into stance and swing periods, periods into different tasks and tasks into different phases.[5,6] Hence, analyzing the different patterns of disturbance in the various phases gives a better understanding of the various abnormalities of gait in children.

Palisano *et al.* described a simple classification to measure gross motor function, the gross motor functional classification system (GMFCS). This was stratified into five levels:[7]

Level I - Walks without restriction, limitations in high-level skills; Level II - Walks without devices, limitation in walking outdoor; Level III - Walks with devices, limitation in walking outdoors; Level IV - Limited mobility indoors, powered mobility outdoors; and Level V - Very limited self mobility, even with assistive technology.

GMFCS was also described for the age groups up to 2 years, 2–4 years, and 4–6 years, between 6 and 12 years and later revised by adding 12–18 years in 2007.

Kinematics is the term used to describe movement without considering the internal or external forces that cause movement. The measures include velocities, trajectories, joint angles of the hip, knee, and ankle. Common points observed in sagittal motion kinematics are hip flexion-extension, knee flexion/extension, ankle movement, and rockers of the foot and initial contact.

Jump gait is characterized by increased hip flexion and knee flexion with slight dorsiflexion at initial contact followed by rapid knee extension and ankle plantar flexion during loading response.[8] Sutherland and David described the knee as being stiff due to overactivity of the rectus femoris muscle with the ankle in plantar flexion whereas Miller[9] described the ankle as being neutral, the rapid knee extension and hip extension were noted in younger age group as reported by Rodda and Graham.[10] Jump knee gait is seen in patients with diplegia, hemiplegia, and quadriplegia and is most commonly seen in younger patients learning to ambulate, however, as the child gains weight and matures it slowly decreases and changes the pattern.[4]

Instrumented gait analysis enhances the understanding of gait abnormality by providing real-time objective data that cannot be appreciated visually or measured on a static physical examination.[8] It provides information that is critical for describing the gait pattern. IGA is performed using a motion analysis system.

Since the few studies in literature describe the gait patterns of jump gait in children with diplegia in the Western population, the authors decided to study the same in the Indian population. The aim of this study is to describe the kinematic characteristics of jump gait in children from Indian population with spastic cerebral palsy with special reference to rockers of the foot-ankle complex.

Study Design

This was a descriptive and retrospective study.

Duration of the Study

The duration of the study was 3 and ½ years. Data were collected from January 2013 to June 2016

Study Setting

Gait Analysis Laboratory and Cerebral Palsy Clinic of the Department of Physical Medicine and Rehabilitation, Government Medical College, Thiruvananthapuram.

Study Population

Clinically diagnosed children with spastic diplegia walking with jump gait, who underwent three-dimensional (3D) gait analysis at the Department of Physical Medicine and Rehabilitation, Government Medical College, Thiruvananthapuram, Kerala, India, during the above period were selected.

Inclusion Criteria

The following criteria were included in this study:

- Children with cerebral palsy having spastic diplegia and walking with jump gait pattern walking with hip flexed, knee flexed, and ankle in equinus).
- Children belonging to GMFCS Level I and Level II.
- Having independent ambulation for >5 m.

Exclusion Criteria

The following criteria were excluded from the study:

- Children with spastic diplegia walking with gait pattern other than jump gait assessed clinically.
- Children with cognitive deficits unable to follow simple instructions.
- Children who were medically unstable or having ongoing seizures.
- Children with spastic diplegia belonging to GMFCS Level III, Level IV, and Level V.

Sample Size

Consecutive sampling was used.

A total of 14 children with spastic diplegia walking with jump gait who satisfied the above criteria and who underwent 3D gait analysis during the above period were included in the study.

METHODOLOGY

Children with spastic cerebral palsy having jump gait as assessed clinically who underwent 3D gait analysis at the study setting were included in the study.

Details of clinical evaluation and report of 3D gait analysis done on children with spastic diplegia walking with jump gait were collected and compiled and entered in a pro forma after informed consent.

All the children continued their standard treatment and rehabilitation such as antispastic and other medications, serial casting, rehab exercises, occupational therapy, and physiotherapy.

Assessment of power, tone, and range of motion of the joints of the lower extremity were given emphasis in the clinical evaluation along with general evaluation.

Goniometer was used for measuring joint angles, medical research council grading for power, and Ashworth grading for spasticity. Further, the 3D gait analysis data acquired and processed on BTS smart DX 600 motion analysis system, at the gait analysis lab of the study setting mentioned, were also compiled. The system consisted of four infrared cameras mounted on the wall, two video cameras, two force platforms embedded into the 5 m walkway.

The process of gait acquisition included recording of anthropometric measurements according to the simple Helen Hayes protocol. Standard weighing scale, measuring tape, and beam calipers were used to capture the measurements. Measurements included calf circumference, leg and thigh lengths, ankle diameter, knee diameter, pelvic depth, anterior superior iliac spine (ASIS) width, weight, and height. After anthropometric measurements were entered into the computer,15 reflective markers were placed on the lower limbs on both right and left sides at the second metatarsal head, lateral malleolus, heel, calf, lateral femoral condyle, middle thigh, and ASIS and one on the sacrum.

The child was made to stand on the force platform for a standing session acquisition followed by a few walking sessions. The best walking sessions were selected, and the data further tracked, elaborated, processed, and report generated. The temporal, distance and clinical data were entered into a pro forma and analyzed. The kinematic data observed were the initial contact of the foot on the floor during initial stance phase, the adequacy of the rockers, (heel, ankle, and toe), knee flexion and extension during swing and stance, hip flexion, and adduction components of the lower extremity.

Analysis

SPSS version 16.0 was used for the statistical analysis which included, mean, standard deviation, *P* value and independent *t*-test was used for determination of differences in the gait parameters against age sex, GMFCS, deformities, and rockers.

On measurement with goniometer, if the child had hip flexion deformity ≥10°, the child was considered to have hip flexion contracture for statistical purposes. So too if the knee flexion contracture was ≥25°, then the child was considered to have knee flexion deformity. Moreover, if the total adductor angle is <80°, then the child was considered to have scissoring or adduction deformity. The child was considered to have equinus if the R1 (first resistance on stretching the gastrocnemius muscle with the knee in extension) was >5° and if the R1 R2 difference was <5°, then the child was considered to have a stiff equinus (static equinus). If the R1 R2 difference was >5°, the child was considered to have dynamic equinus. R1 is the first resistance felt when the ankle was passively stretched to dorsiflexion to assess the gastrocnemius tightness, and R2 is the final tightness after forceful stretching when the knee is extended.

RESULTS AND OBSERVATION

Clinical evaluation and gait analysis report of 14 Indian children with jump gait having spastic diplegia were analyzed. The mean age of the study population was 8.43 ± 4.5 years there were 5 girls and 9 boys. The mean height was 117.8 cm and mean weight was 27.1 kg there were 6 children in the GMFCS I group and 8 children in the GMFCS II group. 2 children had hip deformity >10° and 6 children had knee flexion deformity >25°. 2 had static equinus and 12 had dynamic equinus on the right side and one with static equinus and 13 with dynamic equinus on the left. 2 children had adductor/scissoring deformity at the hip [Tables 1-3 and Figures 1-3].

Table 1: Age distribution in the study group

Age in years	Number of children (%)
<4	2 (14)
5–6	5 (36)
7–12	3 (21)
13–18	4 (29)
Total	14 (100)

Table 2: Sex distribution in the study group

Sex	Number of children (%)
Male	9 (64)
Female	5 (36)
Total	14 (100)

Table 3: GMFCS distribution in the study group

GMFCS	Number of children (%)
I	6 (43)
II	8 (57)
Total	14 (100)

GMFCS: Gross motor functional classification system

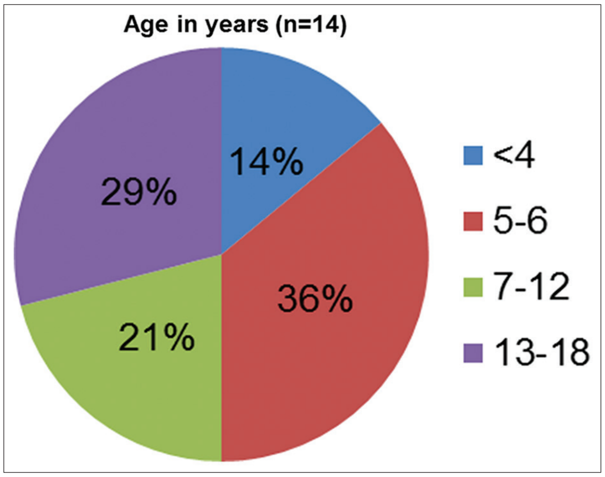

Figure 1: Age distribution in the study group

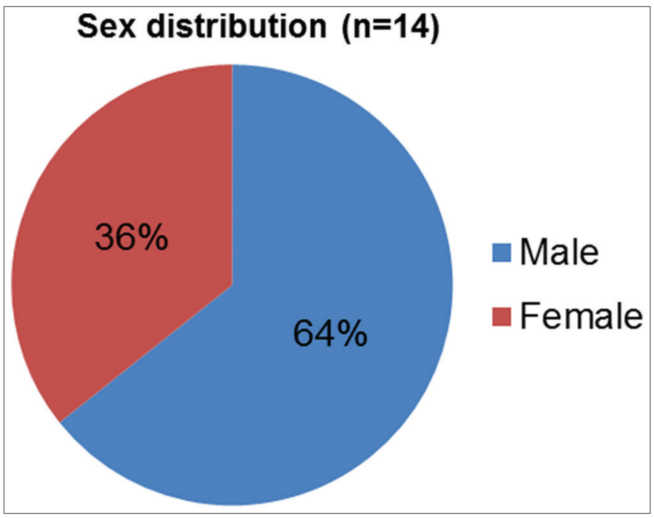

Figure 2: Sex distribution in the study group

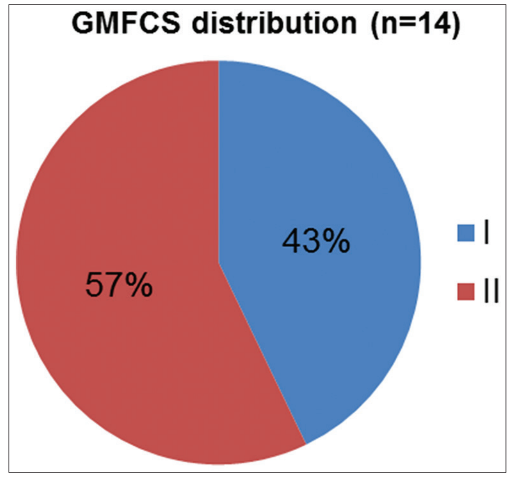

Figure 3: Gross motor functional classification system distribution in the study group

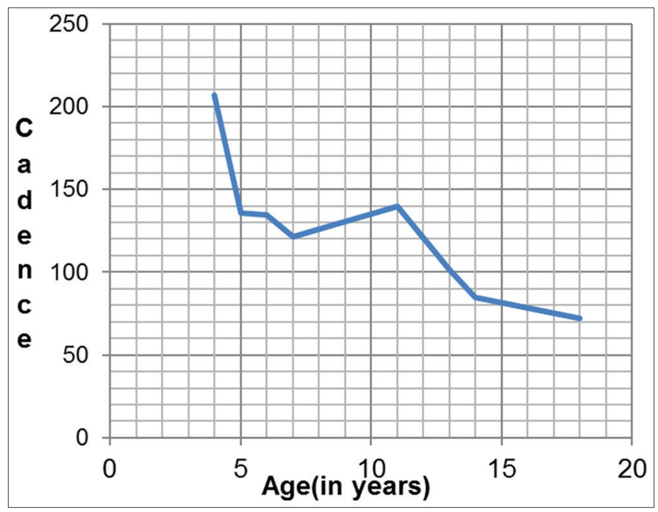

Figure 4: Line diagram showing a variation of cadence with age

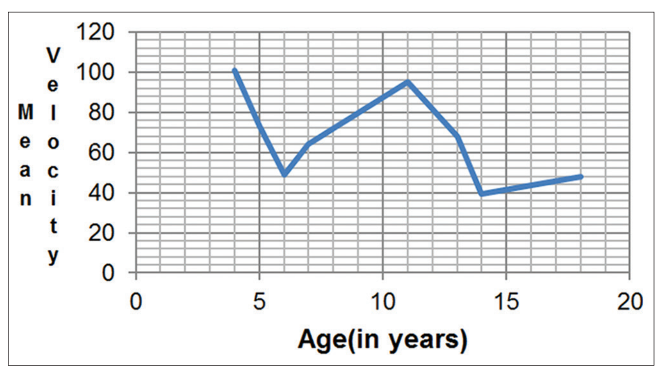

Figure 5: Line diagram showing a variation of mean velocity with age

The mean cadence was 129.77 ± 40 steps per min and the mean velocity was 66.92 ± 23.7 cm per s. The mean stride length was 79.57 cm on the right and 79.92 on the left. The mean step width was 17.3 cm. The step lengths were 36.5 ± 8 cm and 35.21 ± 8 cm on the right and left, respectively.

When the kinematic parameters were separately observed on the right and left lower limbs, there were 28 samples in a total of the 14 children with spastic jump gait included in the study [Figure 4 and 5].

Initial Contact of the Foot during Stance Phase

Fifteen out of 28 legs (53.6%) had the initial contact during stance phase on the midfoot, 5 out of 28 legs (17.9%) had the initial contact on the forefoot, and 8 of the 28 legs (29.5%) had the initial contact on the heel [Tables 4 and 5].

A 7–12 age group had the best heel-toe pattern (37.5% on the heel), and this pattern deteriorated as age advanced. The very young children with jump gait also walked more on their midfoot (75%) and forefoot (25%).

Rockers of the Foot and Ankle

In stance phase heel rockers were absent, and ankle rockers were good in the age group 5–6 and 7–12, thereafter ankle rockers reduced considerably as age advanced. The toe rockers were reasonably good in the 5–6 and 7–12 age group indicating a better gait pattern in this particular age group [Table 6].

Knee Flexion Deformity and Spatiotemporal Characteristics

Independent *t*-test conducted on the spatiotemporal parameters in children with knee deformity (Popliteal angle ≥25°) and those without knee deformity in children with jump gait. It was found that those children with knee deformity had decrease in cadence and mean velocity and an increase in stance and swing time than those without. *P* value of cadence (0.054), mean velocity (0.004), and stance time (0.014) on the left was statistically significant [Tables 7 and 8].

Hip Adduction and Spatiotemporal Characteristics

Hip adduction component was present minimally in 4 out of the 14 children [Table 9].

Table 4: Distribution of initial contacts in the study group

Initial contact	Number of initial contacts (%)
Heel	8 (28)
Mid foot	16 (58)
Fore foot	4 (14)
Total	28 (100)

Table 5: Age wise distribution of initial contacts

Age in years (Legs)	Heel (%)	Mid foot (%)	Fore foot (%)
2–4 *n*=2 (4)		3 (75)	1 (25)
5–6 *n*=5 (10)	1 (10)	9 (90)	
7–12 *n*=3 (6)	4 (66.7)	2 (33.3)	
13–18 *n*=4 (8)	3 (37.5)	2 (25)	3 (37.5)
Total *N*=28	8 (28.57)	16 (57.14)	4 (14.28)

n: Number of children, N: Number of samples

Table 6: Age wise distribution of rockers

Age 2–4 category			
***N*=4**	**Absent (%)**	**Poor**	**Good**
Heel rocker	4 (100)	-	-
Ankle rocker	-	4 (100)	-
Toe rocker	-	-	4 (100)
Age 5–6 category			
***N*=10**	**Absent**	**Poor**	**Good**
Heel rocker	7 (70)	2 (20)	1 (10)
Ankle rocker	-	3 (30)	7 (70)
Toe rocker	1 (10)	2 (20)	7 (70)
Age 7–12 category			
***N*=6**	**Absent**	**Poor**	**Good**
Heel rocker	2 (33.33)	1 (16.67)	3 (50)
Ankle rocker	-	2 (33.33)	4 (66.67)
Toe rocker	-	-	6 (100)
Age 13–18 years category			
***N*=8**	**Absent**	**Poor**	**Good**
Heel rocker	5 (62.5)	1 (12.5)	2 (25)
Ankle rocker	-	8 (100)	-
Toe rocker	2 (25)	2 (25)	4 (50)

Table 7: Knee flexion deformity right side and spatiotemporal characteristics

Parameters	POP <25 R *n*=10	POP ≥25 R *n*=4	*P* value
Cadence (steps/min)	138.760±42.04	107.325±29.58	0.20
Velocity (cm/s)	71.00±26.39	56.75±12.42	0.32
Stance time (s) R	0.5490±0.21	0.7125±0.26	0.25
Stance time (s) L	0.5240±0.18	0.7000±0.23	0.16
Swing time (s) R	0.4040±0.09	0.4900±0.09	0.13
Swing time (s) L	0.4580±0.15	0.4925±0.11	0.69
Stride time (s) R	0.9550±0.30	1.2000±0.35	0.21
Stride time (s) L	0.9360±0.29	1.1900±0.34	0.19
Step length (m) R	0.3610±0.09	0.3700±0.04	0.86
Step length (m) L	0.3560±0.08	0.3425±0.08	0.79
Stride length (m) R	0.8100±0.16	0.7600±0.08	0.58
Stride length (m) L	0.8150±0.15	0.7600±0.09	0.53
Step width (m)	0.1640±0.04	0.1975±0.05	0.22

Table 8: Knee flexion deformity left and spatiotemporal characteristics

Parameters	POP <25 L *n*=10	POP ≥25 L *n*=4	*P* value
Cadence (steps/min)	145.056±37.73	102.28±31.94	0.054
Velocity (cm/s)	79.11±19.52	45.00±11.4	0.004
Stance time (s) R	0.4967±0.14	0.774±0.27	0.028
Stance time (s) L	0.4789±0.11	0.74±0.23	0.014
Swing time (s) R	0.3867±0.07	0.50±0.08	0.022
Swing time (s) L	0.4367±0.15	0.52±0.116	0.289
Stride time (s) R	0.8833±0.20	0.88±0.20	0.22
Stride time (s) L	0.8700±0.19	0.87±0.19	0.22
Step length (m) R	0.3433±0.09	0.34±0.09	0.232
Step length (m) L	0.3589±0.08	0.35±0.08	0.692
Stride length (m) R	0.8044±0.16	0.80±0.16	0.779
Stride length (m) L	0.8022±0.15	0.80±0.15	0.922
Step width (m)	0.1611±0.03	0.19±0.06	0.175

Table 9: Hip adduction deformity and spatiotemporal parameters

Parameters	ADD angle >80° *n*=10	ADD angle ≤80° *n*=4	*P* value
Cadence (steps/min)	141.740±47.70	123.133±37.31	0.43
Velocity (cm/s)	72.80±37.81	63.67±12.86	0.51
Stance time (s) R	0.5400±0.29	0.6267±0.20	0.53
Stance time (s) L	0.5260±0.25	0.6011±0.19	0.54
Swing time (s) R	0.4140±0.08	0.4367±0.10	0.69
Swing time (s) L	0.4260±0.12	0.4911±0.15	0.43
Stride time (s) R	0.9560±0.39	1.06±0.3	0.57
Stride time (s) L	0.9420±0.38	1.04±0.29	0.58
Step length (m) R	0.4200±0.09	0.33±0.06	0.052
Step length (m) L	0.3520±0.07	0.35±0.08	0.99
Stride length (m) R	0.8780±0.17	0.75±0.11	0.12
Stride length (m) L	0.8740±0.16	0.75±0.11	0.14
Step width (m)	0.1720±0.04	0.17±0.04	0.92

Comparison of spatiotemporal parameters in children with hip adduction deformity (<80°) and those without adduction contracture showed that those with decreased hip adduction angle tending to scissoring had decreased cadence, mean velocity, and step length. The swing time and stance time correspondingly increased in children with tighter adductor muscles (*P* values were not significant).

Equinus Deformity and Spatiotemporal Characteristics

Two of the 14 legs on the right side had stiffer equinus as evidenced by gastrosoleus stretch <5° (R1 to R2 <5°), whereas the equinus on the left side was stiffer only on one leg in the 14 examined.

On comparing the spatiotemporal parameters in children with static equinus (R1-R2 <5°) and dynamic equinus (R1-R2 >5°), it was found that those with static equinus had better cadence, mean velocity and step width, correspondingly swing and stance time decreased, so did the step length (*P* values were not statistically significant) [Tables 10 and 11].

Table 10: Gastrosoleus tightness on right side and spatiotemporal parameters

Parameters	Ankle R2–R1 >5 right *n*=12	R2-R1 ≤5 right *n*=2	*P* value
Cadence (steps/min)	122.808±37.04	171.600±46.66	0.11
Velocity (cm/s)	65.08±25.24	78.00±4.24	0.49
Stance time (s) R	0.6275±0.23	0.4050±0.09	0.23
Stance time (s) L	0.6008±0.21	0.4150±0.09	0.26
Swing time (s) R	0.4458±0.08	0.3250±0.10	0.10
Swing time (s) L	0.4925±0.13	0.3200±0.09	0.11
Stride time (s) R	1.0742±0.32	0.7300±0.19	0.17
Stride time (s) L	1.0558±0.31	0.7250±0.20	0.18
Step length (m) R	0.3692±0.08	0.3300±0.05	0.55
Step length (m) L	0.3525±0.08	0.3500±0.014	0.97
Stride length (m) R	0.7992±0.15	0.7750±0.04	0.84
Stride length (m) L	0.8067±0.15	0.7550±0.06	0.65
Step width (m)	0.1717±0.04	0.1850±0.007	0.71

Table 11: Gastrosoleus tightness on left side and spatiotemporal parameters

Parameters	Ankle R1–R2 >5° left *n*=13	R1–R2 ≤5° left *n*=1	*P* value
Cadence (steps/min)	124.023±35.74	204	0.05
Velocity (cm/s)	65.85±24.32	81	0.55
Stance time (s) R	0.6154±0.23	0.34	0.27
Stance time (s) L	0.5915±0.26	0.35	0.28
Swing time (s) R	0.4423±0.08	0.25	0.05
Swing time (s) L	0.4846±0.13	0.25	0.11
Stride time (s) R	1.0585±0.31	0.59	0.17
Stride time (s) L	1.0415±0.30	0.58	0.17
Step length (m) R	0.3692±0.08	0.29	0.37
Step length (m) L	0.3531±0.08	0.34	0.88
Stride length (m) R	0.8000±0.15	0.74	0.71
Stride length (m) L	0.8062±0.14	0.71	0.53
Step width (m)	0.1723±0.04	0.19	0.72

DISCUSSION

This study attempted to describe the kinematic characteristics of jump gait in Indian children with spastic cerebral palsy, belonging to the GMFCS I and GMFCS II category. The main parameters studied were initial contact of the foot during early stance, the heel, ankle, and toe rockers which help move the tibia over the ankle-foot complex during stance, the adductor overactivity, knee deformity and to what extent static or dynamic equinus was present in jump gait and how it affected cadence. In general, cadence and mean velocity decreased with age as it advanced especially after 12 years. The step length and step width also decreased as the child grew older.

It was found that majority of the children in the study group had initial contact on the midfoot (53.6%). Toe rockers were good in all the age group studied for jump gait, however, the rockers deteriorated after 12 years of age. The ankle rockers were also poor in the 13–18 age group. The 7–12 age group had the best rockers.

The hip adduction component was present only in three children probably because the GMFCS III and IV category were not included and of the GMFCS I and II category with jump gait, only two children had classical knee flexion deformity, i.e., >25° during mid-stance phase. Moreover, these children had a slower mean velocity.

The rockers of the foot-ankle complex were assessed as absent, poor, and good on an observational basis in the younger age group of 2–4 years heel rockers were absent, and ankle rockers were poor. However, they all moved on the toe rockers with increasing cadence.

Domagalska *et al*. studied the relationship between clinical, measurement, and gait analysis data in children with cerebral palsy.[11] He described that gait pathology in children does not depend on the static and dynamic contractures of hip and knee flexors and that clinical evaluation and gait pattern need to be treated as independent factors that provide information about the functional problems with gait.

This study revealed that children with hip flexion deformity had decreased cadence, mean velocity, and stride length and increased swing and stride time (*P* value was not significant).

Those children with a popliteal angle >25° also showed decreased cadence, mean velocity. The stance time and swing time of the opposite side increased (*P* = 0.05).

Those with stiffer gastrocnemius muscle apparently had increased cadence when compared with those children with dynamic equinus. (Hence an ankle-foot orthosis could make walking faster for children with a stretchable gastrocnemius).

In this study of the 7–12 age group, the majority had good ankle and toe rockers and half of them also had heel rockers. In the 15–18 age group, heel rockers were absent in majority (62.5%), ankle rocker was poor in all and toe rockers were good in only half the children with jump gait who were older. According to Rab, the most common change with age is from a pattern of toe walking to a pattern with increasing knee and hip flexion and eventually crouch gait.[12]

Studies by Sutherland and Davids describes jump gait as the ankle in equinus, knee, and hip in flexion with anterior pelvic tilt and lordosis, though Miller describes it as ankle being neutral.

Limitations of the Study

Small sample size, only GMFCS I and II were taken. For adductor and knee flexion deformities, the sample size was too small. Further studies need to be done to confirm the findings observed.

CONCLUSION

- Majority of the children with jump gait landed on their midfoot during initial contact.
- The heel-toe pattern or rocker function of the ankle-foot complex was best between the ages 7 and 12 years of age.
- As age advanced to adolescence the rockers deteriorated considerably and so did the step length.
- Knee flexion deformity and equinus deformity slowed the children with jump gait. (However, *P* value was not significant).
- Children with a stiffer gastrocnemius had better cadence than those with dynamic or stretchable equinus.

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