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Original article

Comparison of lower extremity range of motion during walking between children with cerebral palsy and normal children

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Background: Walking is very important for children with cerebral palsy but they lack voluntary coordination of muscle movements. Moreover, affected children have their own pattern of walking which is different from normal walking. Thus, gait analysis is a great tool for diagnosis with the aim to rehabilitate the children as best as possible.

Objective: To compare lower extremity range of motion during walking between children with cerebral palsy and normal children.

Methods: The participants were 15 children with cerebral palsy (5 - 15 years of age). Their motor abilities were classified at level 1 - 3 on the Gross Motor Function Classification System. The control group comprised 15 age–matched normal children. Walking movement was investigated by computerized motion analysis.

Results: There were statistically significant differences in the range of motion of right hip abduction/adduction, knee flexion/extension, and pelvic upward tilt/downward tilt (P = 0.020, 0.006, and < 0.001, respectively) during right foot strike. Likewise, statistically significant differences were observed in the range of motion of knee flexion/extension and pelvic upward tilt/downward tilt (P < 0.001 and 0.001, respectively) during left foot strike. Concerning foot off, statistically significant differences were observed for right hip flexion/extension, right knee flexion/extension, and pelvic upward tilt/downward tilt (P < 0.001, 0.001, and 0.014, respectively) for right foot off. When analyzing left foot off, statistically significant difference were observed for left hip flexion/extension, left abduction/adduction, pelvic forward tilt/backward tilt, and pelvic upward tilt/downward tilt (P = 0.003, 0.006, 0.045, and < 0.001, respectively).

Conclusion: Gait analysis should be included in holistic diagnosis which is not often seen in present medication.

Keywords: Cerebral palsy, walking, computerized motion analysis, gait analysis.

Cerebral palsy is defined as a syndrome of disorders in the development of movement and posture. It is caused by partial pre- or postnatal pathological non-progressive disruption of brain development, i.e. lesions will not spread to other regions of the nervous system. However, this limited to local damage of the brain greatly inhibits normal locomotion of children in their daily lives. [1] The limitation of movement is caused by abnormal muscle and joint function leading to hypertonicity, joint stiffness, skeletal deformation, and muscle weakness. Imbalance and lack of coordination while performing voluntary movements, including lack of selective motor control are easily observed [2] among children with cerebral palsy in everyday activities such as rolling, crawling, and walking. [3] As for any child, walking is very important for affected children but they have a lack of voluntary coordination of muscle movements. Moreover, these children have their own patterns of walking which are different from normal walking; they are known as compensated walking. [4] Unfortunately, compensated walking can cause others problems; gait analysis is, therefore, very important for diagnosis and rehabilitation to achieve the best possible quality of life. [5, 6]

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At present, computerized motion analysis is used to precisely evaluate gait and range of movement, and posture in children with cerebral palsy.[7, 8] However, the application of this highly developed technology is not common in Thailand due to its high costs.

The benefit of the research is knowing the joints' range of motion in children with cerebral palsy while walking, and to evaluate how much it is different or deviates from the joints' range of motion in normal children. It shows the quality of their walking can be used as the data for physical therapy treatment planning.

The aim of this study was to compare lower extremity range of motion during walking between children with cerebral palsy and normal children. The normative data of range of motion during foot strike and foot off would benefit physical therapy treatment in cerebral palsy.

Materials and methods

This analytic cross-sectional study has been approved by the Ethics Committee, Thammasat University. The study was conducted between March and December 2015 and included 15 children with cerebral palsy (5 - 15 years old). Their motor abilities were classified at level 1- 3 on the Gross Motor Function Classification System (GMFCS).[9] The control group included 15 age–matched, healthy children and the inclusion criteria in this group were absence of leg length discrepancy, good health, good communication skills, and compliant behavior. In the cerebral palsy group, participants with joint contracture were excluded as were children who had seizures and/or severe visual and hearing deficits. Joint contractures are measured by passive range of motion. If the joint cannot move during the passive range of motion, it is considered to be joint contracture. The number of required participants was estimated based on effect size = 1.0, confidence = 95%, power 80% and resulted in 30 participants, 15 normal children and 15 children with cerebral palsy.

Before the start of the walking exercises and the computerized motion analysis, all children and their guardians participated in the informed consent process and signed the informed consent form. The children with cerebral palsy received a warm up routine comprising muscle stretching of hip adductors, flexors, and extensors, knee flexors, and ankle plantarflexors which took about 15 - 20 minutes and prepared them for walking.[10] Markers were attached on both body sides of all participants to facilitate computerized motion analysis. The markers were placed at the anterior superior iliac spine, posterior inferior iliac spine, greater trochanter of the femur, lateral epicondyle of the knee, the lower lateral 1/3 surface of the thigh, the lower 1/3 of the shank, lateral malleolus, the second metatarsal head, and the calcaneus at the same height above the plantar surface of the foot as the toe marker. The participants had to walk through the test once before being timed in order to become familiar with the test. Then the ready participants had to walk 10 meters in the set up area where video recording and motion analysis was carried out. While walking, the movement was analyzed by the motion analysis software. At least three acceptable trials were collected for each child. After that, a video of a completed gait cycle was selected for each participant. The Mann-Whitney test was used to determine mean, range, and standard deviation in order to compare the range of motion of the lower limb between normal children and children with cerebral palsy.

Results

The baseline characteristics of the participants showed that the mean age was comparable in the two groups; children with cerebral palsy were 9.9 ± 3.0 years old and normal children were 9.9 ± 3.7 years old (further details can be found in Table 1). The two groups were different in gender distribution with 80% male children in the cerebral palsy group and only 27% male children in the normal children group (Table 1). All children in the cerebral palsy group were classified into level 2 on the gross motor function classification system of children with spastic diplegia cerebral palsy (GMFCS).

The ranges of motion at the hips, knees, ankles, and pelvis during left and right foot strike were recorded and compared between normal children and children with cerebral palsy.[11, 12] During right foot strike, a statistically significant difference was observed in the range of motion of right hip abduction/adduction, knee flexion/extension, and pelvic upward tilt/downward tilt (P = 0.020, 0.006, and < 0.001, respectively) (Table 2). As for the left foot strike, statistically significant differences were observed in the degree of knee flexion/extension and pelvic upward tilt/downward tilt (P < 0.001 and 0.001, respectively) (Table 2).

Likewise, ranges of motion at hips, knees, ankles, and pelvis during left and right foot off were recorded and compared between normal children and children with cerebral palsy. [11, 12] Statistically significant differences during right foot off were observed for hip and knee flexion/extension, and pelvic upward tilt/downward tilt (P < 0.001, 0.001, and 0.014, respectively) (Table 3). As for the left foot off, statistically significant differences in the ranges of motion were observed in hip flexion/extension and abduction/adduction and in pelvic forward/backward tilt, and upward/downward tilt (P = 0.003, 0.006, 0.045, and < 0.001, respectively) (Table 3).

Table 1. Characteristics of normal children and children with cerebral palsy.

Characteristics	**Children with cerebral palsy (n = 15)**	**Healthy children (n = 15)**
Age in years		
Mean ± SD	9.9 ± 3.0	9.9 ± 3.7
Range	5.7 - 14.8	5.0 - 15.0
Sex, n (%)		
Male	12 (80.0)	4 (27.0)
Female	3 (20.0)	11 (73.0)
GMFCS, n (%)		
II	15 (100.0)	-
Type of cerebral palsy, n (%)		
Diplegia	15 (100.0)	-
On anti-spasticity medications, n (%)		
No	14 (93.0)	-
Yes	1 (7.0)	
Spasticity, n (%)		
Both hip adductors	4 (27.0)	
Right ankle plantar flexors	6 (40.0)	-
Left ankle plantar flexors	7 (46.0)	
Tightness/ Shortening, n (%)		
Both hip flexors	4 (27.0)	
Right hip adductors	2 (13.0)	
Left hip adductors	1 (7.0)	
Both knee flexors	11 (74.0)	-
Right ankle plantar flexors	7 (47.0)	
Left ankle plantar flexors	3 (20.0)	

Table 2. The comparison of the range of motion of foot strike between normal children and children with cerebral palsy.

Movement	**Range of motion (Degrees) (Mean ± SD)**					
	Right foot strike			**Left foot strike**		
	Typical children (n = 15)	**Children with cerebral palsy (n = 15)**	***P*- value**	**Typical children (n = 15)**	**Children with cerebral palsy (n = 15)**	***P* - value**
Hip						
Flexion/extension	31.07 ± 6.84	29.53 ± 34.47	0.359	30.33 ± 5.76	31.80 ± 14.26	0.458
Abduction/ adduction	2.43 ± 3.91	-9.66 ± 26.31	0.020*	-0.42 ± 3.90	-0.09 ± 13.22	0.382
Knee						
Flexion/extension	8.88 ± 14.96	23.12 ± 45.91	0.006*	4.54 ± 4.16	25.47 ± 17.18	0.000*
Ankle						
Dorsiflexion/ plantarflexion	-0.42 ± 4.71	-2.58 ± 11.94	0.570	-2.32 ± 6.64	-0.31 ± 10.67	0.541
Eversion/inversion	1.70 ± 2.64	4.00 ± 6.04	0.335	2.38 ± 3.87	4.04 ± 5.32	0.275
Pelvic						
Forward/ backward tilt	3.86 ± 23.18	12.63 ± 9.49	0.337	9.60 ± 6.31	12.63 ± 8.65	0.431
Upward/ downward tilt	2.39 ± 1.78	-5.24 ± 3.55	<0.001*	-0.53 ± 2.13	5.67 ± 5.84	0.001*
Forward/ backward rotation	3.01 ± 4.88	1.54 ± 11.83	0.965	3.86 ± 5.19	9.93 ± 16.62	0.383

*Significant difference (P < 0.05) between groups using Mann-Whitney test

Table 3. The comparison of the ranges of motion of foot off between normal children and children with cerebral palsy.

Movement	Range of motion (Degrees) (Mean ± SD)					
	Right foot off			Left foot off		
	Typical children (n = 15)	Children with cerebral palsy (n = 15)	*P*- value	Typical children (n = 15)	Children with cerebral palsy (n = 15)	*P* - value
Hip						
Flexion/extension	-4.74 ± 6.70	17.54 ± 18.32	< 0.001*	-4.96 ± 6.37	12.33 ± 14.99	0.003*
Abduction/adduction	-3.35 ± 3.70	-5.42 ± 13.19	0.275	-4.92 ± 2.83	3.17 ± 11.71	0.006*
Knee						
Flexion/extension	23.17 ± 7.81	42.83 ± 17.88	0.001*	25.53 ± 7.36	33.03 ± 15.07	0.106
Ankle						
Dorsiflexion/ plantarflexion	-4.94 ± 10.38	-14.75 ± 5.87	0.359	-4.67 ± 6.54	-12.20 ± 22.95	0.930
Eversion/inversion	0.34 ± 8.18	3.29 ± 6.07	0.679	4.00 ± 3.12	1.84 ± 5.61	0.221
Pelvic						
Forward/ backward tilt	2.27 ± 24.91	14.05 ± 10.22	0.084	9.51 ± 5.33	15.80 ± 9.93	0.045*
Upward/ downward tilt	-2.31 ± 1.61	-7.04 ± 5.45	0.014*	-4.19 ± 2.71	4.25 ± 4.35	< 0.001*
Forward/ backward rotation	-4.86 ± 4.24	-10.76 ± 10.69	0.176	-2.86 ± 4.38	-0.56 ± 9.70	0.348

*Significant difference ($P < 0.05$) between groups using Mann-Whitney test

Discussion

Normal ranges of motion for the hip, knee, and ankle from foot strike to loading response phase have been reported as: hip changed from 30 degrees flexion and then turn to hip extension; knee stabilized in extension; and ankle moved from a neutral position to 20 degrees plantar flexion. The results of this study demonstrate that there are statistically significant differences between normal children and cerebral palsy children in the range of motion of knee flexion/ extension and pelvic upward tilt/downward tilt in right and left foot strikes. The normal degree of knee flexion/ extension is approximately near or at zero in the foot strike phase and this was the common result found in normal children. In contrast, excessive knee flexion was commonly observed in children with cerebral palsy due to muscle tightness or shortening of the knee flexors in both the left and right sides (74%).[13] During foot strike, children with cerebral palsy cannot fully stretch their knee due to tightness of knee flexors. This is relevant to the research of Cooney KM, *et al.*[14] This research found that children with cerebral palsy who have pathologic hamstring tightness would have a limitation of knee extension during terminal swing. This is also relevant to the research of Kim CJ, *et al.*[15] They found that there is the increasing range of motion of knee flexion in children with cerebral palsy more than in normal children during stance phase and foot strike. At the same time, a pelvic downward tilt can be observed in the children with cerebral palsy which is caused by weakness of hip abductor muscles[16] whereas a pelvic upward tilt is found in normal children. In addition, a significantly different range of hip abduction/ adduction is only found in the right foot strike. Children with cerebral palsy have a negative range of hip adduction while normal children have a positive range because of their stronger hip abductor muscles. Therefore, normal children are better able to control their hip abduction than children with cerebral palsy while positioning the rear foot on the floor. Furthermore, children with cerebral palsy are affected in their ability to control hip movement by the observed spasticity (27%) and tightness (13%) of the right hip adductors. Interestingly, results for the left foot strike were not statistically significantly different between normal children and children with cerebral palsy because tightness of the left hip adductors in children with cerebral palsy was only 7%. The dominant leg in normal children might have a negative effect.

Angles of hip flexion/extension, ankle dorsiflexion/ plantarflexion, ankle eversion/ inversion, and pelvic forward rotation/backward rotation of right foot strike and left foot strike were not statistically significantly different. The degree of hip flexion of both groups was close to the normal average. Although tightness of hip flexor muscles was observed in children with cerebral palsy, it did not hinder foot strike because hip flexion still occurred when the participants moved. Furthermore, the hip extensors tone in the cerebral palsy group was quite normal, thus the degree of hip flexion was not different from the normal average. Moreover, both groups had a similar range of motion of ankle dorsiflexion/plantarflexion, slightly negative in children with cerebral palsy which means ankle plantar flexion, closer to zero in normal children which means the ankle is in a neutral position. The results are consistent with the spasticity of ankle plantar flexors (40% found on the right and 46% on the left) whereas the tightness of ankle plantar flexors differed between right and left (47% versus 20%, respectively). The mean range of motion of ankle eversion/inversion is comparable in the two groups because the children with cerebral palsy have normal ankles including tone and length of muscles of ankle evertors and invertors are close to the normal average. Likewise, pelvic forward rotation/ backward rotation is comparable in the two groups which means that the children with cerebral palsy are able to process the swing phase as with close as normal children. Pelvic rotation is clearly evident during swing phase leading to increased step length. Concerning pelvic forward tilt/backward tilt, although there was no statistically significant difference, pelvic forward tilt was observed in the majority of children with cerebral palsy but not in normal children. This might be caused by the tightness of hip flexors including weakness of hip and back extensors. [17]

The following 'foot off' which is defined as a rhythm before entering into swing phase will be discussed. Swing phase begins after toe off (pre-swing) in which the forefoot that is in the post position rhythmically kicks off from the ground. In a standard swing phase hip extension will be at 20 degrees, knee flexion at 40 - 50 degrees, and ankle plantar flexion at 20 - 35 degrees. Statistically significant differences were observed between normal children and children with cerebral palsy during right foot off in the ranges of motion of hip flexion/extension, knee flexion/ extension, and pelvic upward tilt/ downward tilt. The range of motion of right hip flexion/extension as observed in normal children leads to normal locomotion. The greater range of motion of the right hip flexion/ extension observed in the children with cerebral palsy is due to weakness of hip extensors and tightness of hip flexors. It causes abnormal gait when the children have to force hip extensors to mobilize kicking their foot off the ground during pre-swing. Typically, right knee flexion/extension is between 40 - 50 degrees in the gait of adults and the study shows that it is less in normal children. However, a greater range of motion of right knee flexion/extension was observed in children with cerebral palsy (74% tightness of knee flexors). Another interesting part of right foot off is the range of motion of pelvic upward/downward tilt. Downward tilt was commonly found in children with cerebral palsy but less in normal children and the reason might be the weakness of hip abductors in the former. Interestingly, no statistically significant difference was observed in the range of motion of pelvic forward/ backward tilt but the range was higher in children with cerebral palsy than normal children as were compensatory movements. This helps cerebral palsy children to more easily draw the forefoot off the ground during pre-swing.

Concerning left foot off, a statistically significant difference was observed in the range of motion of the left hip abduction/adduction which was not seen during right foot off. Hip abduction was found in children with cerebral palsy while hip adduction was evident in normal children. Children with cerebral palsy must control their center of gravity while walking and might use compensatory movements that lead to left hip abduction. This widens the base of support and the children cannot collapse while walking. [18]

This study indicates that children with cerebral palsy have different joint motion patterns from normal children. During foot strike, children with cerebral palsy cannot fully control their hip abduction. Hip adduction occurs and their knee joints cannot fully extend. Also, their pelvic upward tilt is lower than that of normal children. Their pelvic upward tilt is minus. It shows less movement of the pelvis than average while good and efficient walking needs normal movement of the pelvis. During the foot off, children with cerebral palsy cannot fully extend their hip joints. It causes them to have more difficulty than normal children to kick their tiptoes from the ground. Moreover, children with cerebral palsy have less movement of pelvic upward tilt than average. Therefore, they walk less steadily than the normal children do.

This study was designed to be unbiased and to avoid confounding factors. However, there might be other factors that affect the range of motion of walk such as age, gender, and level of GMFCS. Unfortunately, gender distribution is not equal between the two groups and obviously, the level of GMFCS is different between the two groups. It is also clear that some range of motion values have high standard deviations. The range of age is large in both groups and differences in body development might affect the gait. Although all children with cerebral palsy were classified at GMFCS level 2, a variety of gait and movement patterns will have occurred and that might have caused high standard deviations. Likewise, overweight, flatfoot, and scoliosis are factors that could lead to gait variation and should be further analyzed.

While the number of participants satisfied the requirement, it might not have been sufficiently high to prevent random errors. In follow-up studies, the number of participants should be higher to obtain statistically significant and clinically important results.

The results of this research are similar to those of Maas JC, *et al.* (19) who analyzed ten participants with cerebral palsy for ranges of motion of knees and ankles while walking. In the research, a video recorder and a custom-designed hand-held ankle dynamometer were used to record the data. From Josina's research, it was stated that unlike the range of motion of ankle dorsiflexion which decreased, the degree of knee flexion was increased while in the stance phase. In addition, Wolf SI, *et al.* (4), presented data on the increase of pelvic forward tilt during stance phase and showed that this was related to the degree of knee flexion while initial contact happened during stance phase and the cause of this might be the contraction of rectus femoris.

It is important to evaluate the walking ability of children with cerebral palsy because they are not fully able to control body movement. The level of their ability and severity of gait disorder depends on various factors. The limitations should be diagnosed and assessed as early as possible to prevent development of an abnormal musculoskeletal system in the future. Beyond the evaluation from birth history, physical examination, and X-ray diagnosis, gait analysis should be included in a holistic diagnosis which is less seen in the present medication. The results should not be generalized or applied to children with other types of cerebral palsy and different severities. The large age range in both groups is a limitation, possibly a larger sample size is required for higher accuracy. It is suggested that motion analysis is also able to provide information for orthopedic surgery in order to rehabilitate unusual locomotion. (20 – 22) Furthermore, it can be useful for physical therapy treatments.

Conclusion

This study concludes that during foot strike, there are differences of ranges of motion of knee flexion/extension and pelvic upward/downward in both left and right legs between children with cerebral palsy and normal children. During foot off, there are differences of the ranges of motion of hip flexion/extension and pelvic upward/downward in both left and right legs between children with cerebral palsy and normal children.

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Conflict of interest

The authors, hereby, declare no conflict of interest.

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